When distraction is not distracting: A behavioral and ERP study on distraction in ADHD

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Abstract

Objective: Although an increased distractibility is one of the behavioral criteria of Attention Deficit Hyperactivity Disorder (ADHD), there is little empirical evidence that children with ADHD are in fact more distractible than their normal peers.

Methods: We recorded event-related potentials (ERPs) to distracting novel sounds (novels) and standard sounds, (standards) while children performed a visual two-choice reaction time task. Twenty-five children with ADHD were compared with eighteen normal controls (aged 8–12 years).

Results: Children with ADHD showed a larger early P3a (150–250 ms), both in response to the standard and in response to the novel. The late phase of the P3a had a larger amplitude in the ADHD group in the 250–300 ms window compared to the control group, which was only present in response to the novel. Interestingly, the novel reduced the errors of omission in the ADHD group to a greater extent than in the normal control group.

Conclusions: Although children with ADHD show an increased orienting response to novels, this distracting information can enhance their performance temporarily, possibly by increasing their arousal to an optimal level, as indicated by the reduced omission rate.

Significance: These data indicate that distraction is not always distracting in children with ADHD and that distraction can also have beneficial effects.

Keywords: ADHD; Children; ERP; P3a; Distraction; Attention

1. Introduction

One of the behavioral manifestations of children with Attention Deficit Hyperactivity Disorder (ADHD) is their abnormal apparent distractibility (DSM-IV; American Psychiatric Association, 1994). Especially in the classroom, children with ADHD often pay more attention to events happening in and outside the classroom and less attention to their schoolwork than their normal peers. Surprisingly, a number of attempts to prove that children with ADHD are abnormally distractible have been unsuccessful (see for review Douglas and Peters, 1979). Selective or focused attention tasks, such as visual search paradigms with distracters, often do not differentiate children with ADHD from normal controls (Van der Meere and Sergeant, 1988; Mason et al., 2003; Huang-Pollock et al., 2005). However, it has been frequently reported that children with ADHD have greater difficulty in inhibiting conflicting stimuli that are incorporated in a task, i.e. they show poorer performance on Stroop- and Flanker-tasks (Scheres et al., 2004), although the difference in interference control between normal control groups and ADHD groups on the Stroop task is small (see for meta-analysis Van Mourik et al., 2005). Apparent distractibility in the classroom may

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have multiple causes, for example, children with ADHD could have less intrinsic motivation (Carlson et al., 2002), suffer from a failure to inhibit stimuli extraneous to the task (Barkley, 1997), or distractibility could be a functional attempt to modulate underarousal by seeking stimulation (Zentall and Zentall, 1983). Alternatively, children with ADHD could have an abnormally low threshold for the breakthrough of unattended (and usually irrelevant) information, which is found even in children with subclinical attentional problems (Kilpeläinen et al., 1999).

Most distraction or selective attention tasks are not ecologically valid measures of distraction in daily life situations, because in daily life, the distraction that has to be inhibited is outside the task and not conflicting with task demands, for example, a child is doing schoolwork while other children are talking. Escera et al. (1998) developed a paradigm to measure this kind of distraction with event-related potentials (ERPs). This paradigm has been adapted by Gumenyuk et al. (2001) to measure distraction in children. In this paradigm, the child performs a visual task while listening to standard tones and occasionally a novel environmental sound, such as a mooing cow, an engine, or a bell. These sounds should be ignored by the child. Novel and unexpected stimuli are hard to ignore and cause distraction. Behaviorally, this distraction is observed as deterioration in performance in the task as shown by increased reaction times and/or decreased performance accuracy (Escera et al., 1998; Gumenyuk et al., 2004).

At the electrophysiological level, unattended and task-irrelevant novel stimuli elicit a P3a component in adults (Squires et al., 1975; Escera et al., 1998) and children (Cycowicz and Friedman, 1997; Ceponiené et al., 2004; Gumenyuk et al., 2004). The P3a component is thought to reflect an evaluative, conscious aspect of the orienting response and an attentional switch to the novel information (Friedman et al., 2001). The dorsolateral prefrontal cortex has an important role in response to auditory distraction (Campbell, 2005). Both the noradrenergic (Missonnier et al., 1999) and the dopaminergic (Kähkönen et al., 2002) systems have been found to modulate the P3a. Previous studies indicated that the P3a has two subcomponents in adults (see for review Escera et al., 2000) and in children (Ceponiené et al., 2004; Gumenyuk et al., 2004): an early P3a (eP3a) component with its peak latency around 200 ms and a late P3a (IP3a), which peaks at around 300 ms. Ceponiené et al. (2004) suggested that the eP3a might be a receiver of the sensory information and governs the direction of the attentional focus as reflected by the IP3a. The IP3a is thus more closely related to the actual orienting of attention (Escera et al., 2000). Since the latency of the eP3a component is similar to that of the auditory P2 peak, it could be argued that the eP3a is actually an enhanced P2 in response to the physical features of the novel sounds. Although the scalp topography of these two positivities differs (fronto-central for the eP3a and centro-parietal for the P2, see Ceponiené et al., 2002) further studies are needed to clarify whether the generators of the auditory P2 differ from those of the eP3a.

An enhanced IP3a may indicate that too much attention is attributed to the novel stimuli, which may result in increased distractibility at the behavioral level. An enhanced P3a has been found in children with major depression (Lepistö et al., 2004) and in adults with closed head injury (Kaipo et al., 1999). Inconsistent findings have been reported with regard to children with ADHD. Two studies found no differences in P3a response to novel sounds (Holcomb et al., 1986; Kenmer et al., 1996). One study found a reduced P3a in the ADHD group in response to novel visual stimuli (Keage et al., 2006) and another study found an enhanced IP3a and a reduced eP3a in the ADHD group in response to novel sounds (Gumenyuk et al., 2005). A possible explanation for these inconsistent results is that one study (Gumenyuk et al., 2005) used a variety of novels, whereas in other studies the same novel was repeated, reducing the novelty effect with trials.

The P3a to distracting sounds is sometimes followed by a frontally distributed negativity with a latency of 400–700 ms. This negativity was interpreted by Schröger and Wolff (1998) as reflecting the reorienting of attention back to the main task after distraction, and it was labeled as the reorienting negativity (RON). A recent fMRI study indicated that a prefrontal-temporal network including the left superior and right middle temporal cortex, right frontal eye fields, the left inferior frontal gyrus and the right precentral underlies reorienting (Mayer et al., 2006). In children, a similar frontal late negativity (hereafter LN) was found in response to distracting novel sounds, which is sometimes referred to as LN (Gumenyuk et al., 2004). Negative Component (Ceponiené et al., 2004; Määttä et al., 2005), or RON (Wetzel et al., 2004). The LN in children with ADHD has been found to be reduced in comparison to control children (Gumenyuk et al., 2005). Interestingly, Konrad et al. (2006) demonstrated that children with ADHD tend to recruit more fronto-striatal-insular activation than normal controls during reorienting in the absence of behavioral differences, which is explained in the context of neural compensation. Using a different paradigm, it has also been found that children with ADHD have behavioral difficulties in reorienting of attention (Pearson et al., 1991) and in disengaging attention when voluntary control is required (Wood et al., 1999).

Although behavioral distractibility is a major clinical feature of ADHD, little research has been conducted to elucidate the neural mechanisms that underlie this behavioral distractibility in the disorder. The only ERP study that investigated auditory distraction during a visual task in children with ADHD is by Gumenyuk et al. (2005). Their results indicated that children with ADHD showed an enhanced distractibility, both at the behavioral as well as at the electrophysiological levels. This very important finding needs to be replicated and extended, since these authors had only small sample size (10 children in each group) and a small age range (only 8- to 10-year-old
children were included). Therefore, the present study aimed at examining both distraction and reorienting in a larger group of children with a broader age range (8- to 12-year-old) with and without ADHD, by recording ERPs from task-irrelevant standard tones and novel sounds, while children performed a visual demanding task. The visual task was different from the task used in the study of Gumenyuk et al. (2005) in order to make it more suitable for older children. Behaviorally, the hypothesis was tested that novel sounds compared to standard tones would result in a larger deterioration in performance (i.e. increased reaction times and/or decreased performance accuracy) in the ADHD group than in the normal control group. At the psychophysiological level, ERPs were measured to elucidate the neural mechanisms of the presumed distractibility in the ADHD group. Differences in the early P3a after the novel compared with the standard (as found in the study of Gumenyuk et al. (2005)) could be interpreted as abnormalities in directing attention, a relatively larger late P3a in the ADHD group would be evidence that children with ADHD attribute too much attention to irrelevant and distracting information, while a relatively reduced LN would suggest that children with ADHD are less capable of reorienting attention back to the main task after temporary distraction.

2. Method

2.1. Participants

Twenty-five children aged between 8 and 12 years with ADHD were compared with eighteen normal control children. Subject characteristics are summarized in Table 1.

The ADHD group was recruited via an advertisement on a website and via a university affiliated outpatient department for ADHD. They all had a formal clinical diagnosis of ADHD by their health care professional. The control children were recruited from primary schools. None of the children had any neurological, sensory or motor impairment or any other developmental psychiatric disorder. Written informed consent was obtained from the children’s parents prior to the study, and children also had to agree by writing down their name on a permission form. The Ethical Committee of the Vrije Universiteit Medical Centre approved the study.

Parents and teachers completed the Dutch version of the Disruptive Behavior Disorder rating scale (DBD; Pelham et al., 1992; Oosterlaan et al., 2000), which allowed the assessment of symptoms of ADHD and comorbid Oppositional Defiant Disorder of Conduct Disorder. Parent and teacher ratings for the ADHD group had to fall within the clinical range (95th–100th percentile) for the Inattention and/or the Hyperactivity/Impulsivity subscale. Control children were included if they received scores below the 90th percentile on all subscales. In order to confirm the DSM-IV diagnosis of ADHD, the Diagnostic Interview Schedule for Children Version IV (DISC-IV, Shaffer et al., 2000) was administered to the parents of the children with ADHD. Only those children with a DSM-IV diagnosis of ADHD participated in the study. Within the clinical group twenty-two children met the DISC-IV criteria for the ADHD combined subtype and three for the ADHD inattentive subtype. Fourteen children with ADHD were also diagnosed with ODD, and two other children with ADHD also received a diagnosis of ODD and CD.

Hearing was screened at 20 dB. All children had normal hearing. IQ was estimated with two performance and two verbal subtests of the Dutch version of the Wechsler Intelligence Scale for Children, third edition (Weschler, 1991; Kort et al., 2002): Picture Arrangement, Block Design, Arithmetic and Vocabulary. All children had an estimated IQ greater than 70. The mean estimated IQ in the control group (M = 117, SD = 16.20) was higher than in the ADHD group (M = 97, SD = 10.28), [t(41) = 5.02, p < .001]. The children with ADHD taking methylphenidate stopped their medication at least 36 h before testing allowing a complete washout (Pelham et al., 1999). The children were rewarded for their participation with a gift voucher of €7.50.

2.2. Distraction paradigm

The present study employed a modification of the distraction paradigm of Gumenyuk et al. (2001) that is schematically depicted in Fig. 1.

Table 1

<table>
<thead>
<tr>
<th>Subject characteristics for the ADHD and normal control groups</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Whole groups</strong></td>
</tr>
<tr>
<td>NC (n = 18)</td>
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<tr>
<td><strong>Boys/girls</strong></td>
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<tr>
<td><strong>Age</strong></td>
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<tr>
<td><strong>IQ</strong></td>
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Asterisks indicate significant differences between Normal Control and the ADHD group, for the whole groups (third and fourth column) and the selected groups matched on IQ (fifth and last column).

** p < .01.
The experiment consisted of a visual two-choice task in which an irrelevant sound preceded the visual stimulus. The visual stimulus was a colored picture of a runner, which was either turned to the left or to the right. Children were asked to indicate the direction of the runner with a button press. The runner was displayed in the middle of a white screen. The irrelevant sound was presented prior to the visual stimulus through a speaker. The sound was either a 600 Hz tone ($p = .80$) or a novel sound ($p = .20$). All sounds had an intensity of approximately 60 dB. Trials were completely randomized, with the exception that at least three standard tones had to occur between any two successive novel sounds. The novel sounds were 99 different environmental sounds, such as a dog barking or a bell ringing. Each novel sound was presented once.

Every trial began with the presentation of a small fixation cross in the centre of the screen for a random time interval ranging from 0 to 200 ms. The sound was then presented for 200 ms followed by a 100 ms delay. The fixation cross was on during the sound and the delay. Thereafter, the runner was presented for 300 ms. Immediately after presentation of the runner, the fixation cross reappeared for 1200 ms. Children could respond to the runner by pressing a response button with their left or right thumb. The interstimulus interval was on average 1900 ms (range: 1800–2000 ms).

The task consisted of three blocks each of 166 trials. After each block (5 min and 32 seconds) a short break was given. Performance feedback (mean reaction time, percentage correct and percentage incorrect) was given after each block. After the first block, children were told that they did well, but were not in the top three, following the second block they were told that they were third and after the last block that they had won the first prize.

2.3. Electrophysiological recordings

The electroencephalogram (EEG; 0.05–200 Hz, sampling rate 1000 Hz) was recorded at 60 scalp sites using electrode caps with tin electrodes referenced to one ear lobe. The ground electrode was placed on the cheek. Horizontal and vertical eye movements (EOG) were recorded from the outer canthi of each eye and below and above the left eye. Impedances were maintained below 10 kΩ. Pre-processing of the EEG data was performed with scan 4.3 software (Compumedics). After additional filtering (0.25–30 Hz), vertical ocular artifacts were corrected using a subtraction algorithm (Semlitsch et al., 1986). The EEG was re-referenced to the mean of both ear lobes. Epochs were extracted from the continuous data file over a 1000 ms period starting 100 ms before each sound onset. Epochs containing EEG or horizontal EOG artifacts that exceed ±100 µV at any electrode were excluded. ERPs were obtained separately for the tones occurring before a novel (standards) and the novel sounds (novels). Averaged ERPs for standards and novels consisted of 85 epochs on average (at least 43 epochs because one child missed a block) per condition per child. In contrast to earlier studies (e.g. Gumenyuk et al., 2004; Schröger and Wolff, 1998), it was decided to analyze both the standards and the novels instead of the difference wave. The reason for this was that we were interested if there were any differences at baseline (standards) between the groups. Because the overlap of the visual stimuli after the sound was the same after the novel and the standard, this could not cause differences between the novel and the standard. After visual inspection of the grand average ERPs, it was decided to include the electrodes Fz and Cz, and to analyze the mean amplitude of the standards and the novels in seven separate windows of 50 ms starting 150 ms until 500 ms after sound onset. These windows gave better insight into the temporal dynamics of the differences than only one window per component and covered the components of interest: the eP3a, the LP3a and the late negativity.

2.4. Procedure

Following the attachment of the electrode cap and EOG electrodes, the children sat comfortably in a chair in an acoustically and electrically shielded room, which was dimly lit. Stimuli were displayed on a 17-inch monitor at 2.4 meter distance from the child’s eyes. Children were monitored by video during the entire experiment and could communicate with the experimenter in the adjacent room.
via an intercom. Before the experimental task, the children participated in one or two short practice blocks, including twenty trials with feedback on each response and without the novel sounds, until the child fully understood the task requirements. After the practice session, the child was instructed to respond as accurately and as fast as possible to the runner and to ignore the sounds. The experimenter left the room and initiated the task.

2.5. Data analysis

Performance measures included mean response times (MRT), percentage of commission errors and percentage of omission errors. Strategy effects were tested by correlating the percentage of commission errors with MRT. In order to test the hypothesis that the performance of children with ADHD was more easily disrupted by the novels compared to the standards, a repeated measures analysis of variance (ANOVA) was performed with group (ADHD – normal controls) as between subjects factor and condition (standard – novel) as within subjects factor for each of the seven windows separately. The influence of IQ on group effects was investigated by computing correlation coefficients between the mean ERP amplitudes (differences between the novel and the standard for each of the seven windows separately) and IQ for each group separately. Furthermore, partial correlation coefficients were calculated for groups separately to explore if there was a relation between the effect of the novel sound on MRT relative to the standard (novel minus standard) and the mean amplitudes of the ERPs (novel minus standard, all seven windows) while controlling for IQ. Because multiple correlations are performed, only correlations with a p-value < .01 are reported, with an exception of the correlations between MRT and commission errors where alpha was set at .05, because in that analysis, only two correlations were tested.

3. Results

3.1. Performance measures

In the ADHD group, there was no significant correlation between IQ and the difference scores (novel minus standard) on mean reaction time, percentage of commission and omission errors. Thus, IQ did not influence performance differences between the conditions in the ADHD group. In the control group there was a significant correlation between the difference in the percentage of omission errors and IQ (r = .60, p < .01), but no significant correlations between the other performance measures and IQ. In order to control for possible effects of IQ on the performance measures, the groups were matched for IQ (n = 14 in each group), all analyses were performed with these subgroups and with the entire group. Although the results did not differ in terms of significant and nonsignificant effects from the results

<table>
<thead>
<tr>
<th>Performance</th>
<th>Stimuli</th>
<th>Whole groups (Mean (SD))</th>
<th>ADHD (n = 25)</th>
<th>IQ-matched subgroups (Mean (SD))</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT (ms)</td>
<td>Novel</td>
<td>610 (65)</td>
<td>648 (100)</td>
<td>625 (64)</td>
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<tr>
<td></td>
<td>Standard</td>
<td>577 (68)</td>
<td>616 (99)</td>
<td>588 (73)</td>
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<td></td>
<td>Difference</td>
<td>33 (26)</td>
<td>31 (40)</td>
<td>37 (26)</td>
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<tr>
<td>Errors (%)</td>
<td>Novel</td>
<td>11 (7)</td>
<td>16 (10)</td>
<td>10 (6)</td>
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<td></td>
<td>Standard</td>
<td>15 (9)</td>
<td>19 (10)</td>
<td>15 (9)</td>
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<td></td>
<td>Difference</td>
<td>4 (6)</td>
<td>3 (7)</td>
<td>5 (7)</td>
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<tr>
<td>Misses (%)</td>
<td>Novel</td>
<td>0.6 (1)</td>
<td>4 (5)**</td>
<td>0.7 (1)</td>
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<td>Standard</td>
<td>1 (2)</td>
<td>9 (12)**</td>
<td>1 (2)</td>
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<td></td>
<td>Difference</td>
<td>−0.6 (0.8)</td>
<td>−6 (8)**</td>
<td>−0.7 (0.9)</td>
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</table>

Note: Difference, novel minus standard; NC, Normal Controls asterisks indicate significant differences between Normal Control and the ADHD group, for the whole groups (third and fourth column) and the selected groups matched on IQ (fifth and last column).

* p < .05.
** p < .01.
obtained in the entire group, for the sake of completeness, the results of the subgroups are summarized in Table 1. The results described in the text apply to the entire group. In both groups, there was evidence for a speed accuracy trade-off: the correlation between the mean reaction time and errors was \(-.42, p < .05\) in the ADHD group and \(-.59, p < .01\) in the control group, respectively. Children who reacted faster made more errors. However, there was no significant difference between these correlations (correlation test; Preacher, 2002), thus possible performance differences between the groups could not be explained by a difference in response strategy between the groups.

Table 2 presents the mean reaction times, and percentages of commission and omission errors. Condition effects were found for mean reaction time \(F(1,41) = 45.63, p < .0005\), commission errors \(F(1,41) = 11.63, p < .001\) and omission errors \(F(1,41) = 11.89, p < .001\). The children responded slower on the trials after the novels were presented compared to the trials after the standards but made fewer errors of commission and omission on these trials. The ADHD group committed more omission errors overall than the control group \(F(1,41) = 7.34, p < .01\), while there was no difference in mean reaction time and commission errors. A group by condition effect was found for omission errors \(F(1,41) = 7.87, p < .01\). The novel sound was associated with a decrease in errors of omission with 6% in the ADHD group and only with 0.6% in the control group. Although the difference in omission errors between the groups was smaller after novels than after standards, children with ADHD still made more omission errors than controls \(t(41) = 2.89, p < .01\).

### 3.2. Event-related potentials

Fig. 2 displays the ERPs at Fz and Cz for the standard, the novel and the difference wave (novel minus standard) for both groups. The auditory stimulus was presented at 0 ms and the visual stimulus at 300 ms. As can be seen in Fig. 2, the P3a had a biphasic structure with an early phase, the eP3a (150–250 ms) and a late phase, the lP3a (250–400 ms). The eP3a had its maximum amplitude over the fronto-central scalp. The lP3a was more widely distributed than the eP3a and had a central maximum. The LN (400–800 ms) had a wide distribution with a frontal maximum.

Table 3 displays the significant effects of condition, group and their interaction for all selected windows at Fz and Cz and the scalp distribution for the difference wave in both groups. Only significant F-values and effect sizes...
Table 3
Summary of significant effects of the ANOVAs of the ERPs after a novel compared with the standard at Fz and Cz and the scalp distribution of the difference waves for both groups within seven 50-ms time windows.

<table>
<thead>
<tr>
<th>Electrode: Fz</th>
<th>Time Window</th>
<th>Effect</th>
<th>Group</th>
<th>Condition</th>
<th>Group × Condition</th>
<th>Electrode: Cz</th>
<th>Group</th>
<th>Condition</th>
<th>Group × Condition</th>
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<tr>
<td></td>
<td>150–200</td>
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- Group: $\eta^2_p$, $F(1,41)$
- Condition: $\eta^2_p$, $F(1,41)$
- Group × Condition: $\eta^2_p$, $F(1,41)$

Scalp distribution difference wave NC

Scalp distribution difference wave ADHD

Scale (µV)

-15 -10 -5 0 +5 +7 +10

* $p < .05$
** $p < .01$, NC, Normal Controls.
are reported. Condition effects were found for all selected windows: The novel elicited a larger positivity in the windows of the eP3a (150–250 ms) and the IP3a (250–400 ms) and a larger negativity in the windows of the LN (400–500 ms). A group effect was found for the windows of the eP3a (150–250 ms) at Cz: the ADHD group had a larger positivity, both in response to the standard and to the novel. An interaction between Group × Condition was found for the 250–300 ms window at Fz: The novel elicited a larger positivity in the ADHD group in this window than in the control group. This increased positivity reflects that the first part of IP3a is larger in the ADHD group at Fz. The scalp distribution for this window (250–300 ms) shows that this positivity is more widespread in the ADHD group than in the control group.

In order to test whether there was a relation between IQ and the mean ERP amplitudes, correlations were computed in each group between total IQ scores and the difference in amplitude in all selected windows. None of these correlations was significant. These difference windows were also correlated with the difference in reaction time (novel minus standard), while controlling for IQ in order to test if there was a relation between distraction effects at the behavioral level and at the electrophysiological level. Again, none of these correlations reached significance, indicating that there is no direct relationship between performance measures and ERPs.

4. Discussion

The main findings of the present study were that the novel sounds reduced the percentage of errors of omissions in the ADHD group more than in the normal control group and enhanced the mean amplitude of the second part of the P3a (IP3a) to a greater extent in the ADHD group than in the normal control group. First, the performance results are discussed and then the ERP results.

4.1. Performance

Our study showed that irrelevant novel sounds distract children’s performance by increasing reaction time after the occurrence of a novel compared with a standard. This is in line with previous studies on distraction (Escera et al., 1998; Gumenyuk et al., 2004). The increase in reaction time was similar in children with ADHD and normal control children; thus children with ADHD did not disproportionately slow down when distracted. Importantly, it was found that, after a novel sound, both groups committed fewer errors. This finding contrasts with earlier studies on distraction in children, which reported that more errors are committed after distracting sounds (Gumenyuk et al., 2004, 2005). A possible explanation for these contrasting findings might be that, because the task here was designed as a runner’s game, the children were especially focused on speed and, therefore, committed more errors. When a novel sound captured their attention, they automatically slowed down, resulting in less fast guesses. The speed accuracy trade-off effect in both groups supports the idea that children tend to make less errors, if they slow down on this task.

An intriguing finding was that children with ADHD committed fewer omission errors after the occurrence of a novel. Overall, children with ADHD made more omission errors, a finding that has been frequently reported in continuous performance tasks (see for meta-analysis Losier et al., 1996) and is related to various ADHD symptoms including difficulties sustaining attention and being easily distracted (Epstein et al., 2003). The novel sounds in this task could serve as stimulation for children with ADHD by making them more alert and focused on the task resulting in a decreased number of omission errors. That children with ADHD benefit from extra-task distraction has been established in several studies (Zentall and Meyer, 1987; Abikoff et al., 1996; Leung et al., 2000) and can be considered as support for the optimal stimulation theory of ADHD (Zentall and Zentall, 1983) and the cognitive energetic model of ADHD (Sergeant et al., 1999; Sergeant, 2005). The optimal stimulation theory postulates that the performance of children with ADHD benefits from extratask distraction because this increases their arousal to an optimal level. The cognitive energetic model emphasizes that children with ADHD might suffer from an energetical dysfunction and are, therefore, unable to adjust their activation to meet task demands. The reduction of omission errors after a novel can be interpreted as the result of increased activation to a more adequate level. However, it should be noted that there might have been a ceiling effect in the normal control group. The normal control group did not commit many omission errors and thus they had no room for improvement.

4.2. Event-related potentials

The ERPs consisted of biphasic P3a with an early and a late phase (eP3a and IP3a) followed by a LN component, which were visible, both in the raw ERPs as well as in the difference wave. The ADHD group showed a larger positivity at Cz in the 150–250 ms window in response to the standard and to the novel. As stated earlier, it is difficult to separate the eP3a from the P2 component. Enhanced P2 components in ADHD groups compared with normal controls in various tasks were reported by Robaey et al. (1992) and Oades et al. (1996) and might be related to altered automatic information processing in ADHD. Specifically, abnormalities in the P2 amplitude topography and latency in the ADHD group have been interpreted as atypical inhibition of sensory input from further processing (Johnstone et al., 2001). However, the eP3a has been described as a component that is related to govern the direction of the attentional move, which, in turn, would be reflected by the IP3a. Thus, although the latency of the P2 and the eP3a is the same, the functional interpretation is
somewhat different. Following other studies of distraction (Escera et al., 2000; Gumenyuk et al., 2004, 2005), the positivity in the 150–250 ms window in this study is interpreted as reflecting the eP3a, and not the P2. A larger eP3a in the ADHD group could indicate that ‘the call for attention’ is stronger in the ADHD group, both in response to the standard as to the novel. Contrary to our findings, Gumenyuk et al. (2005) found a reduced eP3a in the difference wave (novel minus standard) in the ADHD group compared with the normal control group. Since in that study only the results of the difference wave were presented, it is difficult to compare that finding with our results.

The IP3a in response to the novel compared to the standard was enhanced in the ADHD group at Fz in the 250–300 ms window. This positivity was more widespread than in the control group. This larger positivity in the IP3a window points to a stronger involuntary switching of attention to the novel in the ADHD group. This finding is in line with the results of Gumenyuk et al. (2005). The P3a is known to be modulated by the noradrenergic system (Missonnier et al., 1999) and the dopaminergic system (Kähkönen et al., 2002). A dysregulation in the noradrenergic and dopaminergic systems has been implicated in the psychopathology of ADHD (Biederman and Spencer, 1999; Solanto, 2002; Pliszka, 2005).

Berridge and Waterhouse (2003) suggested that the noradrenergic system might enhance cognitive functioning under ‘noisy’ conditions in which irrelevant stimuli could impair performance, by reducing ‘noise’ and/or facilitating processing of relevant sensory signals. Following this line of reasoning, the enhanced IP3a in response to the novels in the ADHD group could be the result of insufficient noradrenergic modulation of the fronto-subcortical pathways, which could lead to a greater sensitivity to irrelevant stimuli.

Polich and Criado (2006) developed a theoretical model of the P3a and the P3b. They stated that the P3a originates from stimulus-driven disruption of frontal attention engagement during task processing, while the P3b originates when temporal-parietal mechanisms process the relevant stimulus information for memory storage. A P3a can thus be elicited by novel and distracting stimuli across modalities, but also by non-novel stimuli in a difficult odd-ball paradigm (target/standard discrimination) in response to infrequent, irrelevant, but non-novel distracters (Comerchero and Polich, 1998; Polich and Comerchero, 2003).

Both saliency of the distracter as well as task difficulty of the primary task rather than novelty per se contribute to eliciting of the P3a (Polich and Criado, 2006). A P3b is typically elicited by infrequent target stimuli. Interestingly, this task relevant P3b has been found to be reduced in ADHD (Satterfield et al., 1994) indicating that children with ADHD suffer from deficient preferential processing of to be attended stimuli. Methylphenidate, which increases noradrenergic and dopaminergic neurotransmission in the prefrontal cortex (Berridge et al., 2006), has been found to enhance the amplitude of the P3b and to improve performance in ADHD (Jonkman et al., 1997). It is possible that a dysfunction in the noradrenergic and dopaminergic systems in ADHD could lead to an altered balance between the attentional resources in which target stimuli receive less attention, while irrelevant novel stimuli elicit more attention compared to normal controls. Future research is necessary to test this hypothesis and to examine the influence of methylphenidate on the P3a in response to distracting irrelevant stimuli.

No differences were found between the groups for the LN component, which suggests that children with ADHD did not have more difficulty than their normal peers in reorienting their attention back to the task after having been distracted. Konrad et al. (2006) reported that children with ADHD tend to recruit more fronto-striatal-insular activation than normal controls during reorienting in the absence of behavioral differences in reorienting, which is explained in the context of neural compensation. Gumenyuk et al. (2005) did find differences in the LN (a larger LN in an early time window and a smaller LN in a later time window) in an ADHD group compared to a control group. In their study, the differences in the LN in the ADHD group might be related to their increased omission rate after a novel. Perhaps children with ADHD do not have a functional deficit in reorienting of attention, but their reorienting capability may be more dependent on task demands.

Taken together, it may be concluded that children with ADHD show an increased orienting to novel auditory information as indicated by the larger positivity in the IP3a window, but they seem to have normal reorienting abilities. Thus, the distractibility observed in the classroom in children with ADHD could be caused by an enhanced orienting reaction to unattended and irrelevant information, which is probably modulated by the dopaminergic and noradrenergic systems. However, this increased orienting to novels does not necessarily lead to larger behavioral distraction effects in the ADHD group. Instead, the present results provide evidence that the performance of children with ADHD can be improved by temporary distraction, as indicated by the reduced omission rate. Possibly, novels can increase the arousal of children with ADHD to an optimal level (Zentall and Zentall, 1983), which results in improved performance. In this case, the distraction is not detrimental, but has a stimulating effect on the performance accuracy (specifically on omission errors) in the ADHD group.

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References


