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Attention-deficit hyperactivity disorder involves differential cortical processing in a visual spatial attention paradigm

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Abstract

Objective: Inattention is undoubtedly one of the main characteristics of Attention-deficit hyperactivity disorder (ADHD). Nevertheless, a growing corpus of evidence shows that not all attentional processes are affected in this condition. This study aimed to explore the distribution of attentional resources in children with ADHD via a spatially shifted double-oddball visual task.
Methods: We recorded event-related potentials (ERPs) for all visual stimuli. Subjects were instructed to allocate attention in a specific area of visual space while ignoring all stimuli presented outside. Ten male children (age: 9–14; mean = 11.6 ± 2.1) who met DSM-IV criteria for the ADHD combined subtype participated in the study, along with ten age- and sex-matched healthy controls (9–14; mean = 11.2 ± 2.3).
Results: ADHD subjects showed late differential cortical responses to initially suppressed irrelevant stimuli. The amplitude of early N1–P1 components were mainly modulated by stimulus location and showed no significant differences between groups, but a late P300-like positivity was clearly evoked in the ADHD group by peripheral stimuli.
Conclusions: These results suggest that ADHD may not compromise the early attentional spatial filter but rather entails a different distribution of attentional resources at later stages of cortical processing. Perhaps these differences may be attributable to individual differences in attentional mechanisms.
Significance: ADHD may not affect initial focusing of visual attention but rather the allocation of processing resources in later stages.

Keywords: ADHD; Attention deficit; Visual spatial attention; ERP; P300

1. Introduction

Attention-deficit hyperactivity disorder (ADHD) is a very common neuropsychiatric disorder clinically characterized by inattention, impulsivity and hyperactivity (Steinhausen et al., 2003). Great research efforts have been devoted to understanding the physiopathology of this condition. Some etiological factors, both genetic and environmental, have been identified and still appear as major topics of research in ADHD (Castellanos and Tannock, 2002). At the level of neuropsychological evaluation, impairment in some attentional processes was expected to be the main cognitive deficit. In fact, the well-known evaluation of 'sustained attention' by means of continuous performance tasks (CPT) has repeatedly shown an increased number of errors in ADHD subjects (Corkum and Siegel,

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1993). Nevertheless, recent reports of detailed neuropsychological explorations of attentional functions in ADHD suggest that other attentional subcomponents might be spared in this condition (Koschack et al., 2003; Huang-Pollock and Nigg, 2003; Sergeant et al., 2002; Barkley, 1997). ADHD children can even perform better than controls in some attentional tasks that involve divided attention (Koschack et al., 2003). New evidence points to poor inhibitory control as a central factor in explaining ADHD symptoms (Huang-Pollock and Nigg, 2003; Durston, 2003; Sergeant et al., 2002; Barkley, 1997).This deficiency could explain both the deficits in cognitive functioning and impulsive behaviors associated with the disorder (Barkley, 1997).These apparent disagreements highlight the need to revisit how attentional resources are used, distributed and controlled in a condition that is clinically characterized by inattention. The present study explores the amplitude of early and late ERP components which have been described to reflect resource allocation in visual spatial tasks (Luck et al., 1996; Mangun and Hillyard, 1990, 1991).

Due to their high temporal resolution, ERPs have been used frequently to study both normal attention and ADHD. Most visual ERP reports on ADHD focus on the neural correlates of the poor performance in extensive CPT and on its improvement after medication. Behavioral reports on the performance of ADHD children in visuospatial attention tasks suggest a differential pattern of reaction times compared to controls (McDonald et al., 1999), but only few ERP studies focus into spatial attention in this condition (Barry et al., 2003). It has been demonstrated that the amplitude of P1 and N1 components of the ERPs is modulated by the attention allocated to a specific visual stimulus (Barry et al., 2003; Kastner and Ungerleider, 2000; Clark and Hillyard, 1996). This evidence has supported the view of an early spatial filter for attentional selection in the visual system (Clark and Hillyard, 1996). In ADHD, early ERP components P1 and N1 are often described as delayed in latency and reduced in amplitude during visual-spatial attention tasks (Perchet et al., 2001; Steger et al., 2000). This might well be interpreted as a deficiency in the early spatial filter in ADHD. Nevertheless, increased amplitude of early positivities has also been described in children with this condition in other experimental designs, such as categorization and seriation tasks (Robaey et al., 1992). Previous studies have also reported differential amplitude for early ERP components in ADHD and related conditions. Buchsbaum and Wender (1973) reported larger amplitude for N140-P2 in children with the diagnosis of Minimal Brain Damage in a passive presentation paradigm. This finding was also supported by data from hyperactive children's responses to standard stimuli in an oddball paradigm (Callaway et al., 1983). Interestingly, reduced P1 amplitudes have been recorded in response to standard and deviant, but not to novel stimuli, in ADHD subjects (Kemner et al., 1996). This data indicates that the interpretation of the amplitude of early ERP components in ADHD is not always simple because it can be modified by multiple factors, like the type of task or the cognitive strategy used to solve it. This emphasizes the need for more comprehensive designs to study attentional processes in ADHD.

Another ERP component frequently used to study attention and ADHD is a late positive deflection referred to as the P300. A delayed latency and decreased amplitude of the P300 is the most usual finding in ADHD studies (Barry et al., 2003). Jonkman et al. (2000) used a double-task paradigm to compare attentional capacity between ADHD and control children. Subjects had to solve two versions of a primary task (easy–hard) while they were passively viewing an oddball task. They found that control subjects had an increase of P300 amplitude to deviants from the easy to the hard version of the primary task. This increase was not found in ADHD subjects. This difference was not evident in the responses to 'novel targets' in which they found that P3 amplitudes decreased from the easy to the hard task to the same extent in both groups. They interpreted these results as indicative of a deficiency in capacity allocation rather than of a capacity shortage in ADHD children. They suggested that both ADHD and control subjects might 'have the same amount of extra capacity at their disposal, but the ADHD children did not, or were not able to invest it in the task when task demands increased'.

These results could also be indicative of a differential pattern of distribution of attentional resources in ADHD. It seems apparent that this differential pattern would become more evident under conditions of high attentional demands and task complexity. But ADHD children also have poorer results in simpler everyday tasks. The DSM-IV criteria describe that ADHD children "often do(es) not follow through on instructions..." and "fail to understand instructions". Exploring the amplitude modulation of ERP components sensitive to attention in a task that does not necessarily pose high attentional demands could give us more information about whether this differential pattern is only present when attentional capacity is challenged or if it is a manifestation of a usual style of resource allocation in this disorder. Investigations in this direction may lead to a better understanding of this highly prevalent condition.

In the present study, we designed a non-simultaneous visual double-oddball task intermixed in time and shifted in space to assess the children's ability to concentrate attention in a specific area of the visual field where they would have to distinguish between two stimuli (relevant-infrequent and irrelevant-frequent). They were asked to selectively ignore any stimulus presented outside this area. A permanently visible frame served as a spatial cue for the intended focus of attention. In accordance with this instruction, we anticipated a stimulus selection strategy based first on spatial location (spatially valid/spatially invalid) and second on stimulus relevance (relevant-infrequent and irrelevant-frequent). This was also anticipated to be reflected in a specific pattern of amplitudes of the