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Emotional distraction in boys with ADHD: Neural and behavioral correlates

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ABSTRACT

Although, in everyday life, patients with attention deficit hyperactivity disorder (ADHD) are frequently distracted by goal-irrelevant affective stimuli, little is known about the neural and behavioral substrates underlying this emotional distractibility. Because some of the most important brain responses associated with the sudden onset of an emotional distracter are characterized by their early latency onset and short duration, we addressed this issue by using a temporally agile neural signal capable of detecting and distinguishing them. Specifically, scalp event-related potentials (ERPs) were recorded while 20 boys with ADHD combined type and 20 healthy comparison subjects performed a digit categorization task during the presentation of three types of irrelevant, distracting stimuli: arousing negative (A−), neutral (N) and arousing positive (A+). Behavioral data showed that emotional distracters (both A− and A+) were associated with longer reaction times than neutral ones in the ADHD group, whereas no differences were found in the control group. ERP data revealed that, compared with control subjects, boys with ADHD showed larger anterior N2 amplitudes for emotional than for neutral distracters. Furthermore, regression analyses between ERP data and subjects' emotional ratings of distracting stimuli showed that only in the ADHD group, emotional arousal (ranging from calming to arousing) was associated with anterior N2: its amplitude increased as the arousal content of the visual distracter increased. These results suggest that boys with ADHD are more vulnerable to the distracting effects of irrelevant emotional stimuli than control subjects. The present study provides first data on the neural substrates underlying emotional distractibility in ADHD.

1. Introduction

The ability to remain goal oriented in the face of irrelevant distracting stimuli is crucial for successful adaptive functioning. This ability is thought to depend on two closely interrelated and mutually dependent attentional mechanisms (Corbetta, Patel, & Shulman, 2008; Corbetta & Shulman, 2002). On the one hand, voluntary top-down processes are triggered and developed by knowledge, expectation and current goals (e.g., read a book for an exam). On the other hand, involuntary bottom-up processes are driven by stimulus features such as novelty or significance (e.g. a wasp that appears suddenly while reading the book). Interestingly, emotional stimuli, salient and signal events by definition, have been shown to be prominent distracters that can efficiently capture attention in a bottom-up fashion, thereby disrupting the focus on goal-relevant information (Carretié, Hinojosa, Martin-Loeches, Mercado, & Tapia, 2004; Carretié, Hinojosa, Mercado, & Tapia, 2005; Vuilleumier & Schwartz, 2001; Öhman, Flykt, & Esteves, 2001).

An increased susceptibility to distraction is currently one of the behavioral diagnostic criteria of attention-deficit/hyperactivity disorder (ADHD; American Psychiatric Association, 2000). Indeed, the presence of heightened levels of distraction in ADHD is believed to be associated with broad impairment across multiple domains, including cognitive functioning (e.g., disrupting the ability to maintain information in working memory: Higginbotham & Bartling, 1993; Marx et al., 2011), interpersonal relationships (e.g., making difficult to follow the sequence of rules in social activities: Maedgen & Carlson, 2000), academic or work performance (e.g. making careless mistakes in school or job activities: Shifrin, Proctor, & Prevatt, 2010), and health (e.g., increasing distraction-related accidents and associated injuries: Barkley & Cox, 2007). However, experimental evidence of enhanced distractibility in ADHD is equivocal. Whereas some behavioral and electrophysiological data suggest that individuals with ADHD are more distractible than healthy comparison subjects (Gumenyuk et al., 2005; Mason, Humphreys, & Kent, 2005; Radosh & Gittelman, 1981; Rosenthal

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& Allen, 1980), others have reported that patients with this disorder are not affected by irrelevant distracting stimuli to a greater extent than controls (Booth et al., 2005; Huang-Pollock, Nigg, & Carr, 2005; Jonkman et al., 2000; Meere & Sergeant, 1988). A recent study has even shown that, in certain circumstances, the presence of auditory distracters could improve the performance of children with ADHD (van Mourik, Oosterlaan, Heslenfeld, Konig, & Sergeant, 2007). In any case, it should be mentioned that research on this topic is scarce, particularly in comparison with the large body of data on the neural mechanisms underlying the reduced top-down inhibitory control in ADHD (Albrecht et al., 2008; Dimoska, Johnstone, Barry, & Clarke, 2003; Liotti, Pliszka, Perez, Kothmann, & Woldorff, 2005; Pliszka, Liotti, & Woldorff, 2000; Rubia et al., 1999), which has been traditionally proposed as the core deficit of this disorder (Barkley, 1997). However, growing evidence indicates that this deficit in inhibitory control is not present among all patients with ADHD and, in some cases, is preceded and caused by other processing deficits (Banaschewski et al., 2004; Brandeis et al., 1998; McLoughlin et al., 2010; Willcutt, Doyle, Nigg, Faraone, & Pennigton, 2005). This evidence has led to question whether inhibition is the central deficit in ADHD and to look for the involvement of other psychopathological processes, including bottom-up and affective mechanisms (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Nigg & Casey, 2005; Sergeant, 2005; Sonuga-Barke, 2002).

It should be also noted that previous studies on attentional deficits in ADHD have relied heavily on emotionally neutral visual distracters, such as letters, numbers and geometric shapes (Booth et al., 2005; Huang-Pollock et al., 2005; Jonkman et al., 2000; Mason et al., 2005). In real social situations, however, maintaining goal-directed attention in the face of salient affective distracters is often needed. Convergent evidence from hemodynamic and electrophysiological studies suggests enhanced neural responses to emotional stimuli relative to neutral ones, even when these stimuli are not consciously perceived (Carretié et al., 2005; Vuilleumier & Schwartz, 2001; Whalen et al., 1998). For example, a number of investigations have reported amplified responses to emotional visual events, involving structures such as the amygdala and the extrastriate visual cortex as well as early and late electrophysiological responses such as N2 and P3 (see reviews by Olofsson, Nordin, Sequeira, & Polich, 2008; Vuilleumier, 2005). Therefore, employing emotional stimuli may help to evoke clearer distraction effects in conditions simulating real social environments. Furthermore, the idea of incorporating emotional stimuli in the characterization of ADHD fits well with current models that emphasize that multiple psychopathological processes and neural pathways are implicated in this disorder, including cognitive (e.g., attention, inhibition and working memory) and affective (emotion and motivation) processes as well as top-down (voluntary) and bottom-up (involuntary) mechanisms (Castellanos et al., 2006; Nigg & Casey, 2005; Sergeant, 2005; Sonuga-Barke, 2002; see also Sonuga-Barke, De Houwer, De Ruiter, Ajzenstzen, & Holland, 2004). From this perspective, the poor ability of ADHD patients to remain focused on a task in the presence of irrelevant emotional distracters could arise not only from a hypofunction of the brain processes associated with cognitive control of distraction, but also from a hyperfunction of brain processes related to the bottom-up response to affectively laden stimuli. In support of this, a recent fMRI study has shown that adolescents with ADHD displayed amygdalar hyperactivity during subliminal presentation of fearful faces (Posner et al., 2011b). However, to the best of our knowledge, no study has yet addressed the effect of emotional irrelevant stimuli on ongoing cognitive processes in children with ADHD.

Due to their high temporal resolution that allows neural processes to be tracked in milliseconds, event-related potentials (ERPs) are particularly useful for elucidating the neural basis underlying emotional distraction in ADHD. The main reason for this is that some of the most important brain responses associated with the sudden onset of an emotional distracter are characterized by their rapidity (early latency onset) and brevity (short duration), and thereby can only be detected by using a temporally agile physiological signal such as electroencephalography (EEG). One ERP component that seems particularly well suited for studying emotional distractibility in the visual modality is the anterior N2, a brain electrical response occurring between 200 and 400 ms after stimulus onset that presents its maximum amplitude over frontal scalp regions. Numerous studies have shown this component to be enhanced for unfamiliar, novel visual stimuli as well as for highly emotional events (Carretié et al., 2004; Chong et al., 2008; Daffner et al., 2000; Kenemans, Verbaten, Melis, & Slangen, 1992; Liddell, Williams, Rathjen, Shevrin, & Gordon, 2004; Rozenkrants & Polich, 2008). Remarkably, it has recently been reported that, unlike subsequent positive components, the amplitude of the anterior N2 to this type of stimuli is neither modulated by the degree of task-relevance of the eliciting stimulus nor by the direction of subjects' controlled attention (Chong et al., 2008; Tarbi, Sun, Holcomb, & Daffner, 2011; see also Carretié et al., 2004 and Liddell et al., 2004). Therefore, this component responds to novel and emotional events even when they are not relevant for the task and occur outside the focus of attention. In light of this evidence, this anterior N2, which is thought to be functionally distinct from the frontocentrally distributed control-related N2 mainly elicited by executive control paradigms (see Folstein & Van Petten, 2008 for a review on this issue), seems to reflect automatic detection of highly significant stimuli (Chong et al., 2008; Daffner et al., 2000; Liddell et al., 2004; Tarbi et al., 2011). To our knowledge, no study has examined it in ADHD.

Following the anterior N2, a large positive deflection over centro-parietal regions is often observed. This posteriorly distributed positivity has been variously called P3, P3b, LPP or LPC, and has generally been associated with more controlled stages of processing (Chong et al., 2008; Kenemans et al., 1992; Liddell et al., 2004). For instance, P3b is thought to reflect the processing of task-relevant events, including stimulus categorization/evaluation and memory updating (Donchin, 1981; Kok, 2001; Polich, 2007; Verleger, 1998). ERP studies of patients with ADHD have frequently shown a reduction in the amplitude of P3b to task-relevant stimuli (Barry, Johnstone, & Clarke, 2003; Brandeis et al., 2002; Jonkman et al., 2000). Within the context of emotion research, this component (often termed LPP) has been shown to be sensitive to manipulations requiring voluntary control processes. Indeed, it has been been proposed as a neural marker of top-down emotion regulation in both adults and children (Dennis & Hajcak, 2009; Moser, Hajcak, Bukay, & Simons, 2006). Interestingly, a reduced amplitude of LPP has recently been found in patients with ADHD when they asked to inhibit their responses to negative emotions (Köchel, Leutgeb, & Schienle, 2012). Hereafter, we will use the term late positive complex (LPC) to describe this family of posteriorly distributed positivities associated to a greater extent than previous components with controlled and conscious processes.

The present study aimed at elucidating the neural and behavioral mechanisms underlying emotional distraction in children with ADHD. To this end, ERP and behavioral data were recorded from boys with ADHD combined type and healthy comparison controls while they performed a digit categorization task while three types of irrelevant, distracting stimuli were presented: arousing negative (A−), neutral (N) and arousing positive (A+). Specifically, behavioral measures consisted of reaction times (RTs) and error rates in the cognitive task. Distraction caused by the irrelevant emotional stimuli would be mirrored in an impoverishment of current task performance (i.e., longer RTs and/or higher error rates for emotional versus neutral distracters). Neural measures consisted