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What does distractibility in ADHD reveal about mechanisms for top-down attentional control?

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ABSTRACT

In this study, we attempted to clarify whether distractibility in ADHD might arise from increased sensory-driven interference or from inefficient top-down control. We employed an attentional filtering paradigm in which discrimination difficulty and distractor salience (amount of image "graying") were parametrically manipulated. Increased discrimination difficulty should add to the load of top-down processes, whereas increased distractor salience should produce stronger sensory interference. We found an unexpected interaction of discrimination difficulty and distractor salience. For difficult discriminations, ADHD children filtered distractors as efficiently as healthy children and adults; as expected, all three groups were slower to respond with high vs. low salience distractors. In contrast, for easy discriminations, robust between-group differences emerged: ADHD children were much slower and made more errors than either healthy children or adults. For easy discriminations, healthy children and adults filtered out high salience distractors as easily as low salience distractors, but ADHD children were slower to respond on trials with low salience distractors than they did on trials with high salience distractors. These initial results from a small sample of ADHD children have implications for models of attentional control, and ways in which it can malfunction. The fact that ADHD children exhibited efficient attentional filtering when task demands were high, but showed deficient and atypical distractor filtering under low task demands suggests that attention deficits in ADHD may stem from a failure to efficiently engage top-down control rather than an inability to implement filtering in sensory processing regions.

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1. Introduction

Attention deficit hyperactivity disorder (ADHD) is the most common childhood mental disorder, affecting between 5% and 10% of children worldwide (Faraone, Sergeant, Gillberg, & Biederman, 2003). Hyperactivity, impulsivity, and inattention are all major behavioral symptoms of ADHD. However, while many studies have documented that ADHD children are impaired in executive functions, including response inhibition, working memory, and conflict resolution (Bush et al., 1999; Casey et al., 1997; Doyle, 2006; Pliszka et al., 2006; Rubia, Smith, Brammer, Toone, & Taylor, 2005; Schulz et al., 2004; Vaidya et al., 2005), the nature and extent of attention deficits in ADHD remain controversial. Although ADHD children are typically slower and more variable to respond to cued targets (Nigg, Swanson, & Hinshaw, 1997; Novak, Solanto, & Abikoff, 1995; van der Meere & Sergeant, 1988), ADHD children have not previously been reported to be impaired at filtering out irrelevant distractors. Healthy and ADHD children exhibit similar patterns of slowed responses to

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relevant targets when distractors are present (Booth et al., 2005; Huang-Pollock & Nigg, 2003; Huang-Pollock, Nigg, & Carr, 2005; Huang-Pollock, Nigg, & Halperin, 2006; Mason, Humphreys, & Kent, 2003; Mason, Humphreys, & Kent, 2005; Nigg et al., 1997; Novak et al., 1995; Oberlin, Alford, & Marrocco, 2005; van der Meere & Sergeant, 1988). This has led several researchers to question whether selective attention is a core deficit in ADHD or whether attentional problems are secondary to deficits of alertness (Huang-Pollock et al., 2005) or other executive processes, including inhibition (Barkley, 1997). The current study aimed to better characterize the nature of attention deficits in ADHD, viewed from the context of the biased competition model of attention (Desimone & Duncan, 1995; Kastner & Ungerleider, 2000; Kastner & Ungerleider, 2001).

According to this model, limited neural and cognitive resources necessitate privileged processing of some sensory inputs and associated responses at the expense of others. Limited capacity of cortical sensory regions leads to bottom-up, perceptual interference from competing stimuli (Desimone & Duncan, 1995; Kastner, De Weerd, Desimone, & Ungerleider, 1998; Moran & Desimone, 1985; Reynolds, Chelazzi, & Desimone, 1999) such that distractors reduce the magnitude and efficiency of neural and behavioral responses. However, stimulus-driven sensory competition can be overcome by top-down, intentional feedback from a network of prefrontal and parietal regions (Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999; Kastner & Ungerleider, 2000, 2001). But while prefrontal and parietal cortex can mediate sensory competition in visual regions, these top-down sources have their own capacity limits. For example, performance on tasks that draw heavily on executive functions – such as tasks with high working memory load – can deteriorate due to insufficient prefrontal capacity to support efficient attentional filtering. (Lavie & DeFockert, 2003; Lavie, 2005). In the current study, we hoped to gain insight into the functional locus of attention deficits in ADHD. Specifically, is distractibility caused by increased competition in sensory cortex, decreased capacity of cognitive control regions, or deficient feedback from control areas to sensory regions? Furthermore, if ADHD can be shown to selectively impair bottom-up or top-down processes, then our findings would provide evidence for modularity and independence of sensory competition and top-down attentional control.

To isolate sensory-level and top-down components of distractor filtering, distractor salience and task difficulty were both parametrically manipulated in an orthogonal fashion. To probe sensory interactions, we manipulated perceptual load by varying distractor salience. Increasing distractor salience has been shown to diminish perceptual responses to target stimuli in ventral stream visual areas (Desimone & Duncan, 1995; Moran & Desimone, 1985; Reynolds et al., 1999). To test the integrity or efficiency of top-down control regions, we manipulated discrimination difficulty in a face discrimination task. We believe that task difficulty was a measure of cognitive load because (1) the face discrimination task involved a comparison of a presented face to an iconic image; (2) the judgment was based on slight differences between morphed face images rather than low-level visual features such as oriented edges or shape; and (3) perceptual decision-making has been shown to be mediated by regions of frontal cortex (Heekeren, Marrett, Bandettini, & Ungerleider, 2004).

Healthy children (age 8–13), ADHD children (age 8–13), and healthy adults practiced a face discrimination task and their perceptual threshold was measured in a staircase procedure. This allowed us to tailor task difficulty to each individual's perceptual threshold. What behavioral patterns were expected for ADHD children? First, if distractibility in ADHD children results from deficient filtering mechanisms in sensory areas, we would expect to see distractor-dependent behavioral deficits. These would manifest as greater interference from high salience distractors than from low salience distractors in ADHD, compared to controls. An inability to filter out the suppressive effects of distractors in sensory areas should produce steeper RT *x* distractor salience slopes in ADHD than healthy subjects, similar to the effects of lesions of extrastriate visual processing areas V4 and TEO (Buffalo, Bertini, Ungerleider, & Desimone, 2005; De Weerd, Peralta, Desimone, & Ungerleider, 1999; Gallant, Shoup, & Mazer, 2000). We would not expect sensory-driven filtering deficits to be influenced by discrimination difficulty. Alternatively, if distractibility in ADHD results from decreased prefrontal and parietal capacity for top-down modulation, we would expect a different pattern of results. Specifically, more challenging tasks should create more competition for limited resources, and, in turn, greater decrements in distractor filtering in ADHD relative to healthy children. Similarly, if distractibility is due to diminished strength of top-down control, then high salience distractors, which cause the largest sensory interference, would require the strongest top-down control. Thus performance in ADHD relative to healthy children would be most affected by high salience distractors, especially for resource–intensive difficult discriminations. Finally, if distractibility is not due to diminished capacity or strength of top-down signals, but instead reflects a heightened threshold for recruiting top-down control, then ADHD children should be more distractible when deployment of selective attention is under endogenous control and not task-driven. In this instance, we expected that ADHD children would be most distractible when performing easy compared to hard discriminations.

The current study focuses primarily on differences between healthy and ADHD children. However, neurocognitive deficits in ADHD have been attributed to neurodevelopmental immaturity. Thus, for two reasons, inclusion of data from healthy adults also clarifies the nature of any detected performance differences between ADHD and healthy children. First, because selective attention has been studied more extensively with adults than children, most theories of attention are based on data from adults. Inclusion of healthy adults in the current study provides a benchmark against which healthy and ADHD children can be compared, facilitating integration of current theories focused narrowly on attention and on ADHD. Second, data in healthy adults clarifies potential developmental influences on task performance, which in turn shapes views of ADHD as arising from neurodevelopmental immaturity (Shaw et al., 2007).