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Allocentric but not egocentric visual memory difficulties in adults with ADHD may represent cognitive inefficiency

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ABSTRACT

Attention Deficit Hyperactivity Disorder (ADHD) has often been conceptualized as arising executive dysfunctions (e.g., inattention, defective inhibition). However, recent studies suggested that cognitive inefficiency may underlie many ADHD symptoms, according to reaction time and processing speed abnormalities. This study explored whether a non-timed measure of cognitive inefficiency would also be abnormal. A sample of 23 ADHD subjects was compared to 23 controls on a test that included both egocentric and allocentric visual memory subtests. A factor analysis was used to determine which cognitive variables contributed to allocentric visual memory. The ADHD sample performed significantly lower on the allocentric but not egocentric conditions. Allocentric visual memory was not associated with timed, working memory, visual perception, or mental rotation variables. This paper concluded by discussing how these results supported a cognitive inefficiency explanation for some ADHD symptoms, and discussed future research directions.

1. Introduction

There are multiple views regarding the etiology of Attention Deficit Hyperactivity Disorder (ADHD). The more prevalent theories suggest problems with inhibition (Barkley, 1997a, b), reduced working memory (Pennington and Ozonoff, 1996), and a more general executive dysfunction model (Brown, 2002, 2006). These views are all consistent with the diagnostic criteria set forth by the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (American Psychiatric Association, 2000), and the recently released Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (American Psychiatric Association, 2013). These theories are also relatively consistent with behavioral observations (Barkley et al., 2002; Barkley and Murphy, 2010) with evidence that working memory deficits may also be contributing to observed problems with inhibition and variable attention span such as impulsively committing an act, losing track of others' conversations, and similar difficulties (Alderson et al., 2010).

On the other hand, there have typically been weak correlations between behavior rating scales of ADHD symptoms and performance on tests of executive functioning (Barkley et al., 2002, 2008; Barkley and Murphy, 2010). Furthermore, while some studies have supported relationships between ADHD and difficulties with inhibition, attention, and working memory (Antshel et al., 2010; Epstein et al., 1998; Forbes, 1998; Gropper and Tannock, 2009), the effect sizes have been moderate, and many individuals with ADHD did not show executive dysfunction (Nigg, 2013; Willcutt et al., 2005). Most of the executive functioning measures were reliant on processing speed (Advokat et al., 2007; Lipszyc and Schachar, 2010), and several studies suggested that slower reaction times and reaction time variability were more strongly associated with ADHD than actual omission, commission, or other outright executive functioning errors (Advokat et al., 2007; Alderson et al., 2007; Bedard and Tannock, 2008; Metin et al., 2013). Working memory difficulties appeared a bit more consistent according to some meta-analyses (Kasper et al., 2012; Martinussen et al., 2005). However, this was difficult to distill from processing speed demands since working memory material was typically presented at a standardized rate which may negatively affect some who are unable to retain this rate. In one of the more obvious examples of this confound, performance on a paced auditory serial addition test became disproportionately lower as the speed of presentation increased among ADHD subjects (Katz et al., 1998). Furthermore, genetic and familial studies suggested measures of reaction time variability, and processing speed variables showed the strongest genetic contribution to ADHD compared to non-timed working memory and inhibition variables (Kuntsi et al., 2006; Nigg et al., 2004).

Together, such findings have led to the suggestion that an executive dysfunction model may be an insufficient explanation for ADHD (Borella et al., 2013; Castellanos et al., 2005; King et al.,

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2007; Nigg et al., 2004; Sergeant, 2000). A number of authors have put forth an alternative hypothesis that ADHD symptoms emerge from an underlying cognitive inefficiency, perhaps related to difficulties with fluctuating or mismatched internal energy levels (King et al., 2007; Metin et al., 2013; Sergeant, 2005; Sergeant et al., 2003; Van der Meere, 2005). From this perspective, executive dysfunction arises from the inefficient use of information to make appropriate decisions, as reflected by a tendency for those with ADHD to have slow rather than very rapid inaccurate responses on tests (Metin et al., 2013; Van der Meere, 2005).

1.1. *Cognitive inefficiency*

Though there are variations in definitions, cognitive efficiency may be generally defined as the degree of effort and/or time required to complete a task in the desired or optimal manner (Hoffman and Schraw, 2009, 2010). From this perspective, cognitive inefficiency occurs when an individual needs to exert a relatively greater degree of effort and/or time to complete a task than would be required by the more typical person within the same situation. This definition is particularly revealing within the context of ADHD. For example, adults with ADHD typically have more difficulty completing work in a timely manner and may be perceived as being inefficient by co-workers (Halbesleben et al., 2013). While one may infer that this inefficiency could be related to distractibility or poor response inhibition, a recent study suggested that task completion time represented a general cognitive inefficiency among those with ADHD and was not explained by either impulsivity or degree of executive functioning demands (Metin et al., 2013).

The concept of cognitive inefficiency has also received support from neuroimaging studies. Resting state functional MRI (fMRI) studies have found abnormalities within several large scale brain networks among those with ADHD (Castellanos and Proal, 2012; Cortese et al., 2012; Konrad and Eickhoff, 2010). Furthermore, MRI volume studies have shown that white matter volume was lower among ADHD subjects (Amat et al., 2006; Castellanos et al., 2002), and diffusion tensor imaging studies have found less cohesive white matter tracts among ADHD subjects (Hamilton et al., 2008; Konrad and Eickhoff, 2010; Makris et al., 2008; Pavuluri et al., 2009). Together these studies suggest inefficient intracerebral communication may be an underlying factor that contributes to reduced cognitive efficiency.

Cognitive inefficiency has typically been demonstrated by slower processing speed and variable reaction times. Such inefficiency may also be demonstrated in other ways. Specifically, if cognitive inefficiency arises from abnormal brain connectivity, then tasks which rely on a greater degree of network connectivity should be more problematic among those with ADHD than similar tasks which require less connectivity. Furthermore, it would be important to demonstrate cognitive inefficiency outside the realm of timing-based measures as it is possible that such measures could be confounded by motor control difficulties that may be present among ADHD patients (Johnson et al., 2010; Lavasani and Stagnitti, 2011). While several recent studies suggested a stronger relationship between ADHD and processing inefficiency than executive dysfunctions, many of the tasks incorporated had some degree of executive functioning component (Borella et al., 2013; Halperin et al., 2008; Lipszyc and Schachar, 2010; Metin et al., 2013; Salum et al., 2014; Skirbekk et al., 2011). Therefore it would further strengthen the argument for an underlying cognitive inefficiency within ADHD if the tasks had no or minimal executive functioning demands.

1.2. *Visual memory*

In reviewing the literature for cognitive domains that had the potential for being distilled from executive functions, we chose a visual memory paradigm to assess cognitive inefficiency for several reasons. First, researchers had previously raised the question of whether long term visual memory difficulties represented a specific ADHD cognitive phenotype since this is sometimes a problem among ADHD samples (Shang and Gau, 2011). However, the visual memory tests which supported that idea (Barnett et al., 2009; Gropper and Tannock, 2009; Johnson et al., 2001; Muller et al., 2007; Shang and Gau, 2011) were confounded by skills typically problematic among ADHD samples such as fine motor control (Johnson et al., 2010; Lavasani and Stagnitti, 2011) and working memory demands (Barnett et al., 2009; Kibby and Cohen, 2008). Furthermore, while the studies purported to be using long term visual memory rather than visual working memory tasks, all the tasks incorporated relied on single rather than repeated exposure to tasks. As a result, problems with attention span and working memory would interfere with any long term memory storage that used those measures. Thus, it is not really possible to determine whether the difficulties exhibited by individuals with ADHD were due to attention span, working memory, long term visual memory difficulties, or perhaps cognitive inefficiency due to these memory tasks simultaneously relying on various cognitive domains.

Another reason we chose to study visual memory was that we had access to a visual memory test, the Brown Location Test (BLT), which controls for attention and working memory difficulties by using five learning trials (Brown et al., 2007, 2010). It also has delayed recall trials that occur 20 min after the learning trial to measure long term visual memory. The test does not require any drawing abilities thereby reducing fine motor and organization demands. The memory stimuli consists of 12, individually presented dot locations on a non-grid random circle array that reduces the chances of using verbal strategies (see Fig. 1 for a simplified example). Furthermore, each individual dot is presented for 4 s which minimizes processing speed and timed visual scanning demands. The most relevant aspect to the current study is that the memory test has different delayed recall perspectives (Brown et al., 2007, 2010).

Specifically, the BLT test has two different long delayed free recall conditions. The first is an egocentric condition (recall from the originally learned perspective) that occurs 20 min after the end of the learning trials and the subject is asked to indicate which circles previously contained red dots. This recall occurs in the same position in which the dot locations were originally encoded. This task typically takes less than 1 min to complete, depending upon the certainty of the subject. Immediately following the egocentric condition, an allocentric visual memory condition (recall from a novel perspective) occurs. In this condition, the display is rotated 90° and the subject is asked to indicate the position of the red dots as they were presented before the display

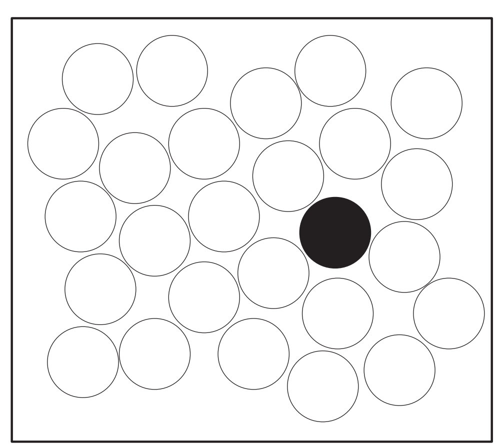

Fig. 1. Simplified example of the circle array with a dot location.