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# Visuospatial working memory underlies choice-impulsivity in boys with attention-deficit/hyperactivity disorder

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ABSTRACT

The present study examined the directional relationship between choice-impulsivity and separate indices of phonological and visuospatial working memory performance in boys (aged 8–12 years) with ($n = 16$) and without ADHD ($n = 19$). Results indicated that high ratings of overall ADHD, inattention, and hyperactivity were significantly associated with increased impulsivity and poorer phonological and visuospatial working memory performance. Further, results from bias-corrected bootstrapped mediation analyses revealed a significant indirect effect of visuospatial working memory performance, through choice-impulsivity, on overall ADHD, inattention, and hyperactivity/impulsivity. Collectively, the findings suggest that deficits of visuospatial working memory underlie choice-impulsivity, which in turn contributes to the ADHD phenotype. Moreover, these findings are consistent with a growing body of literature that identifies working memory as a central neurocognitive deficit of ADHD.



## 1. Introduction

Attention-deficit/hyperactivity disorder (ADHD) is characterized by deficits of inattention and/or hyperactivity/impulsivity (Kessler et al., 2006; Shiels et al., 2009) and affects approximately 3% to 10% of school-aged children (Barkley, 2006; Scahill & Schwab-Stone, 2000). ADHD-related impulsivity is particularly problematic, as it is predictive of social impairment (Gadow et al., 2000), increased rates of aggressive and externalizing behavior (Gaub & Carlson, 1997), future criminal behavior (Babinski, Hartsough, & Lambert, 1999), arrests (Murphy, Barkley, & Bush, 2002), substance abuse (Verdejo-Garcia, Lawrence, & Clark, 2008), and suicidal behavior (Patros et al., 2013).

Previous examinations of ADHD-related impulsivity have adopted methodology from cognitive research that provides two major models of the construct: rapid-response impulsivity (Dougherty, Bjork, Huckabee, Moeller, & Swann, 1999) and reward-delay impulsivity (Swann, Bjork, Moeller, & Dougherty, 2002). Rapid-response impulsivity is the more commonly investigated construct in ADHD research and is characterized by quick-inaccurate responses during tasks that necessitate careful investigation of stimuli prior to initiation of a response (Dougherty et al., 1999). Despite strong internal consistency, test–retest reliability (Wostmann et al., 2013), and convergent validity with rating scale measurements of impulsivity

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(e.g., $r$ = .43; Swann et al., 2002), the ecological validity of these laboratory-based tasks is relatively weak when compared to tasks that measure the less frequently examined construct of reward-delay impulsivity (Solanto et al., 2001).

Developmental (Olson, Schilling, & Bates, 1999), behavioral (Sonuga-Barke, Taylor, Sembi, & Smith, 1992), social (Muraven & Baumeister, 2000), and clinical (Swann et al., 2002) research typically operationalizes reward-delay impulsivity as a choice for immediate-smaller reinforcement over delayed-larger reinforcement via a choice-impulsivity task. Performance on choice-impulsivity tasks often serves as an index of children's aversion to delayed contingencies (i.e., delay aversion; Thorell, 2007), and/or ability to delay gratification (Mischel, Shoda, & Rodriguez, 1989) and exhibit self-control (Logue, 1988; Logue, King, Chavarro, & Volpe, 1990). Therefore, to limit potential for construct confusion, the current study will use the term *choice-impulsivity* when describing preference for immediate-small reinforcers. This moniker is preferred, since it refers to an observable behavior without connoting an underlying causal process (e.g., delay aversion).

Previous examinations indicate that both children (Dalen, Sonuga-Barke, Hall, & Remington 2004; Solanto et al., 2001) and adults (Hurst, Kepley, McCalla, & Livermore, 2011) with ADHD exhibit deficits on choice-impulsivity tasks, evidenced by more frequent selection of immediate-smaller reinforcement relative to delayed-larger reinforcement. These findings have been reliably demonstrated across various iterations of the prototypical choice-impulsivity task, including the Maudsley Index of Delay Aversion (Kuntsi, Stevenson, Oosterlaan, & Sonuga-Barke, 2001), flower-delay task (Sonuga-Barke et al., 1992), and delay discounting tasks (Rachlin, Raineri, & Cross, 1991; Hurst et al., 2011). Further, in contrast to studies of rapid-response impulsivity, the ecological validity of findings from choice-delay tasks is relatively strong (Solanto et al., 2001).

Several models of ADHD provide competing explanations for the manifestation of ADHD-related choice-impulsivity, particularly with respect to the centrality of neurocognitive domains. For example, Barkley's (1997) seminal unifying theory of ADHD suggests that deficits of behavioral inhibition – the ability to stop and/or withhold a prepotent response – underlie impairments in higher order executive functions that guide behavior. Sonuga-Barke's (2003) dual-pathway model of ADHD similarly acknowledges the role of inhibition deficits, but adds that children with ADHD also exhibit choice-impulsivity due to a general aversion to delayed rewards (i.e., delay-aversion). In contrast, the functional working memory (WM) model of ADHD hypothesizes that ADHD-related choice-impulsivity is an outcome of underlying WM impairments (Rapport et al., 2008).

WM is an executive function that allows for the temporary storage, maintenance, and manipulation of verbal and visuospatial information (Baddeley, 2007), and is essential to problem solving (Bühner, Kröner, & Ziegler, 2008), evaluation of choices (Corbin, McElroy, & Black, 2010), and communication with long term memory to reference previous experiences (Ranganath, Johnson, & D'Esposito, 2003). Not surprisingly, WM deficits are associated with increased choice-impulsivity (Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008; Romer et al., 2009). However, despite a moderate amount of research that has identified choice-impulsivity in children with ADHD (Antrop et al., 2006; Marx, Pieper, Berger, Habler, & Herpertz, 2011; Solanto et al., 2001; Thorell, 2007), and a wealth of research that suggests large-magnitude WM deficits in children with ADHD relative to TD children (Kasper, Alderson, & Hudec, 2012), there is a paucity of literature that has examined the relationship between ADHD-related choice-impulsivity and WM deficits, and findings have been relatively equivocal.

Findings from previous correlational studies, for example, suggest that ADHD-related choice-impulsivity is not significantly associated with WM performance on the noisy book task (Sonuga-Barke, Dalen, & Remington, 2003) or Digit Span subtest from the WISC-III (Sonuga-Barke, Bitsakou, & Thompson, 2010). In contrast, a more recent study aggregated performance scores from visuospatial (Find a Phone Task) and phonological (Children's Size-Ordering Task and Backward Digit Span subtest) WM measures to create a composite WM score that was significantly-negatively correlated with choice-impulsivity (Sjowall, Roth, Lindqvist, & Thorell, 2013). Although variability in sample characteristics (e.g., age, intelligence, and gender distributions) likely contributed to between-study discrepancies in findings across these studies, it is also probable that task-specific variables contributed to the equivocal findings. For example, the WM tasks used by Sonuga-Barke et al. (2010) exclusively examined phonological processes, whereas findings from Sjowall et al. (2013) reflect the combined contribution of both phonological and visuospatial WM. Previous experimental (e.g., Westerberg, Hirvikoski, Forssberg, & Torkel, 2004) and meta-analytic (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005) findings have provided strong evidence that ADHD-related WM deficits are more pronounced in the visuospatial system, relative to the phonological system. Consequently, the non-significant correlations reported by Sonuga-Barke et al. (2010) may reflect a problem of restricted range (a greater range of scores is expected when visuospatial tasks are utilized). To that end, it is noted that the small-magnitude of Sjowall et al.'s (2013) reported correlation ($r$ = .28) between WM and choice-impulsivity may reflect a suppression effect, such that a larger-magnitude correlation is expected when visuospatial and phonological performance is examined separately.

Discrepant findings across previous studies might also reflect the degree to which central executive (i.e., the *working* component of WM; Baddeley, 2007) demands varied across experimental tasks reified as measures of WM. This point is particularly important, as previous experimental (Rapport et al., 2008) and meta-analytic (Kasper et al., 2012) findings suggest that ADHD-related WM deficits are primarily associated with impaired central executive functioning, rather than storage/rehearsal processes. However, with the exception of the Children's Size Ordering Task, which requires children to temporarily store and mentally re-order a list of items by size (Sjowall et al., 2013), the Noisy Book Task, Find a Phone Task, and Digit Span task used in previous studies (Sjowall et al., 2013; Sonuga-Barke et al., 2003, 2010) likely placed minimal