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Attention problems, phonological short-term memory, and visuospatial short-term memory: Differential effects on near- and long-term scholastic achievement

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ABSTRACT

The current study examined individual differences in children's phonological and visuospatial short-term memory as potential mediators of the relationship among attention problems and near- and long-term scholastic achievement. Nested structural equation models revealed that teacher-reported attention problems were associated negatively with composite scholastic achievement (reading, math, language), both initially and at 4-year follow-up in an ethnically diverse sample of children ($N = 317$). Much of this influence, however, was attenuated by phonological short-term memory's contribution to near-term achievement and visuospatial short-term memory's contribution to long-term achievement. Domain-specific reading and math models showed similar results with some exceptions. In all models, measured intelligence made no contribution to later achievement beyond its initial influence on early achievement. The results contribute to our understanding of the mechanisms associated with individual differences in children's scholastic achievement, and have potential implications for identifying early predictors of children at risk for academic failure, and developing remedial programs targeting phonological and visuospatial short-term memory deficits in children with attention problems.

Attention problems have been of foremost concern to educators, clinicians, and researchers due to their near- and long-term adverse academic consequences. Attention problems are a primary or associated feature of most child psychological disorders and a prominent feature of attention-deficit/hyperactivity disorder (ADHD; Barkley, 2006). Children diagnosed with attention deficits, for example, score lower on standardized achievement tests relative to their typically developing peers ($d = .71$; Frazier, Youngstrom, Glutting, & Watkins, 2007), and between 7% and 44% and 15% and 60% meet criteria for reading and math disabilities, respectively (Faraone et al., 1993; Frick et al., 1991; Mayes & Calhoun, 2006; Shaywitz, Shaywitz, Fletcher, & Escobar, 1990; Willcutt & Pennington, 2000). Near-term difficulties also include fewer completed assignments (DuPaul, Rapport, & Perriello, 1991), lower grade point averages, more failing grades, and higher grade retention rates (for reviews, see Barkley, 2006; Frazier et al., 2007).

The long-term academic consequences associated with attention problems in children are similarly disabling. Inattentive symptoms at age eight correlate negatively with teacher-rated achievement at 18-month follow-up (Diamantopoulou, Rydell, Thorell, & Bohlin, 2007), and findings gleaned from 13- and 17-year longitudinal studies reveal that 23–32% of children diagnosed with attention deficits fail to complete high school. In addition, significantly fewer enter (22% vs. 77%) and complete college (5% vs. 35%) compared to their typically developing peers (Barkley, Fischer, Smallish, & Fletcher, 2006; Mannuzza, Klein, Bessler, & Malloy, 1993; Mannuzza, Klein, Bessler, Malloy, & Hynes, 1997). In adulthood, attention problems and academic failure are associated with functional impairment as reflected in lower socioeconomic status, poor job performance, and unstable employment (Barkley et al., 2006; Mannuzza et al., 1993). These adverse academic and occupational outcomes appear to be independent of co-occurring conduct problems and IQ (Fergusson & Horwood, 1995; Fergusson, Lynskey, & Horwood, 1997; Frick et al., 1991; Hinshaw, 1992).

The well-established relationship between attention problems and children's near- and long-term scholastic achievement is based primarily on attention scores from factor analytically derived rating scales (e.g., Achenbach, 1991). These informant reports serve as a primary source for diagnosing attention deficits in children (Rapport, Kofler, Alderson, & Raiker, 2008), and nearly always contain a mixture of items that reflect inferences about children's visual attention to task, behavioral correlates of inattention, and secondary outcomes associated with attention problems. For example, the attention problem scale of the commonly used Teacher Report Form (Achenbach, 1991) contains several items that reflect academic correlates of presumed underlying attentional problems (e.g., 'poor school work', 'difficulty learning'). The reliance on subjective judgments of overt behaviors – assumed to be manifestations of multifaceted, covert

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processes – introduces a significant confound into studies examining the relationship between attentional problems and objectively measured long-term academic outcomes. As a result, it is difficult to disentangle the relative contribution of covert cognitive processes and their assumed overt behavioral correlates to long-term academic outcomes, or determine the extent to which previous reports of the attention/achievement relationship reflect overlap between predictor (e.g., teacher-rated 'underachieving'/'not working up to potential') and outcome variables (e.g., standardized academic achievement).

To date, only one longitudinal study has examined the extent to which differences in children's long-term scholastic achievement reflect deficient cognitive processes as opposed to the behavioral manifestations of these processes. Specifically, Rapport, Scanlan, and Denney (1999) simultaneously modeled the impact of vigilance, phonological short-term memory, and teacher-rated classroom behavior and attention problems on long-term scholastic achievement. In that study, phonological short-term memory was the strongest predictor of long-term scholastic achievement. In addition, teacher-rated attention problems no longer predicted long-term scholastic achievement after accounting for this relationship. These findings are not surprising given the well-established relationship between phonological short-term memory and scholastic achievement.

Phonological short-term memory is responsible for the temporary storage and rehearsal of auditory or visually encoded verbal material, and is considered the 'memory' component of phonological working memory (Engle, Tuholski, Laughlin, & Conway, 1999).[1] As such, phonological short-term memory is integrally involved in the development and acquisition of academic skills, and independently contributes to math and reading achievement over and above its association with working memory (Engle et al., 1999, Swanson & Kim, 2007). Similarly, phonological short-term memory is associated with overall measures of reading and math performance (Durand, Hulme, Larkin, & Snowling, 2005; Gathercole, Alloway, Willis, & Adams, 2006; Hulme, Goetz, Gooch, Adams, & Snowling, 2007; Swanson & Kim, 2007), and uniquely predicts word recognition skills (Hulme et al., 2007; Swanson & Howell, 2001) and reading comprehension in children (Cain, Oakhill, & Bryant, 2004, Sesma, Mahone, Levine, Eason, & Cutting, 2009; Swanson, 1994). Importantly, the relationship between phonological short-term memory and scholastic abilities has been demonstrated in preschoolers, children, adolescents, and adults (Bull, Espy, & Wiebe, 2008; Engle et al., 1999; Swanson, 1994; Swanson & Kim, 2007).

Despite methodological refinements over previous investigations of attention problems and long-term scholastic achievement, Rapport et al. (1999) failed to consider the potential role of visuospatial short-term memory. Visuospatial short-term memory is responsible for the temporary storage and rehearsal of non-verbal visual and spatial information, and contributes uniquely to children's learning over and above both visuospatial working memory and phonological short-term memory (Maybery & Do, 2003). For example, visuospatial short-term memory is associated with speech production (van Daal, Verhoeven, van Leeuwe, & van Balkom, 2008) and visual and spatial reasoning (Kane et al., 2004). It also contributes to a wide range of mathematical competencies in children (Maybery & Do, 2003), adolescents (Reuhkala, 2001), and adults (Engle et al., 1999). In addition, visuospatial short-term memory correlates more closely than phonological short-term memory with mathematical competence (Maybery & Do, 2003), and discriminates between children with and without mathematical disabilities (Berg, 2008).

The impact of near-term achievement on long-term achievement must also be considered in longitudinal models. Specifically, the extent to which phonological short-term memory, visuospatial short-term memory, and teacher-reported attention problems continue to contribute to later scholastic achievement beyond their initial impact on near-term achievement was not investigated by Rapport et al. (1999) and remains unknown. The importance of controlling for near-term achievement is highlighted by a recent meta-analysis demonstrating that children's early achievement was the strongest predictor of later academic achievement (Duncan et al., 2007). In addition, a two-year investigation showed that children's IQ did not predict later academic achievement after accounting for near-term academic achievement (Alloway, 2009). Whether this mediation model can adequately explain the relationship between attention problem ratings and long-term scholastic achievement remains unknown, although current evidence indicates that early attention problems partially influence later achievement through their direct effects on early academic development (Rabiner, Coie, & Conduct Problems Prevention Research Group, 2000). Collectively, previous investigations have explained individual differences in long-term scholastic achievement as a function of early phonological short-term memory, achievement, or teacher-rated attention problems, but no study to date has concurrently investigated the explanatory power of these factors and visuospatial short-term memory for predicting longitudinal scholastic outcomes.

A final limitation of the Rapport et al. (1999) study was that attention problem ratings were modeled as a predictor rather than an outcome or correlate of short-term memory problems in children and adolescents. This relationship, however, merits scrutiny. Children's short-term memory and ability to focus attention develop in parallel during early childhood, and serve as a foundation for the later development of the complex cognitive abilities that are critical for successful scholastic achievement (Garon, Bryson, & Smith, 2008). For example, voluntary control over attentional shifts and the ability to hold a mental representation for a few seconds both emerge around 6 months of age (Rothbart & Posner, 2001). By age 2, children are able to shift attention between external events and internal representations, as well as temporarily hold multiple phonological and visuospatial stimuli in mind over a delay (Nielsen & Dissanayake, 2004). These abilities increase rapidly in capacity and duration during the ensuing years, continue to develop in concert (Gathercole, 1998; Tillman, 2010), and are interrelated functionally throughout childhood and adolescence. For example, extant studies suggest that attention is intricately involved in visuospatial rehearsal (Awh & Jonides, 2001), and that attentional resources are limited by phonological short-term memory capacity (Hecht, Torgesen, Wagner, & Rashotte, 2001). In addition, exceeding children's phonological and visuospatial short-term storage capacity is associated with increased rates of observed inattentive behavior (Kofler, Rapport, Bolden, Sarver, & Raiker, 2010) and poorer attentional filtering of irrelevant information (Cowan, Morey, AuBuchon, Zwilling, & Gilchrist, 2010). Finally, phonological and visuospatial short-term memory deficiencies are identified frequently in children diagnosed with attention problems (Brocki, Randall, Bohlin, & Kerns, 2008; Cornoldi et al., 2001; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Rapport et al., 2008; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Collectively, extant evidence indicates that attention, phonological short-term memory, and visuospatial short-term memory are distinct but interrelated predictors of children's near- and long-term scholastic achievement. No study to date, however, has concurrently investigated the explanatory power of these factors for predicting the longitudinal scholastic outcomes of children and adolescents.

The present study uses a series of nested structural equation models to test three empirically driven hypotheses regarding the interrelationships among individual differences in children's phonological/visuospatial short-term memory, teacher-rated attention problems, and near- and long-term scholastic achievement. The models were tested initially using a composite index of achievement consisting of reading, mathematics and language measures. Domain-specific models

[1] Short-term memory and working memory are distinct cognitive systems (Alloway, Gathercole, & Pickering, 2006; Baddeley, 2007) that are highly interrelated (Alloway et al., 2006; Engle et al., 1999), and show a pattern of increasing convergence across childhood (Tillman, 2010).