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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).

(reading, math) were examined subsequently based on past findings demonstrating distinct contributions of phonological and visuospatial short-term memory abilities to specific academic domains. An initial model (Fig. 1a) was created to test the hypothesis that the continuity between teacher-rated attention problems and long-term achievement is mediated by near-term achievement (Rabiner et al., 2000), and to determine whether IQ contributes to long-term achievement after accounting for its effects on near-term achievement (Alloway, 2009; Rapport et al., 1999). A second model (Fig. 1b) was constructed to test the hypothesis that phonological and visuospatial short-term memory abilities attenuate the relationship between teacher-rated attention problems and long-term achievement through their influence on near-term achievement (Engle et al., 1999). No specific hypotheses were offered concerning the potential contributing effects of these pathways on the relationship between attention problem ratings and near-term achievement. A third model (Fig. 1c) tested the hypothesis that phonological and visuospatial short-term memory would contribute directly to long-term scholastic achievement after accounting for their impact on near-term achievement (Rapport et al., 1999). Finally, the relationships between phonological/visuospatial short-term memory and long-term achievement were hypothesized to be moderately stronger for domain-specific models (i.e., phonological with reading, visuospatial with math) relative to composite achievement models (Gathercole, Pickering, Knight, & Stegmann, 2004).

1. Method

1.1. Participants

The sample consisted of 325 children (146 males, 179 females) between 7 and 16 years of age ($M=10.67$, $SD=2.39$) attending public and private schools in Honolulu (Oahu), Hawaii. Approximately 72% of the state's population resides in the city and county of Honolulu (U. S. Bureau of the Census, 1992). Schools were selected based on available data suggesting that their ethnic and sociodemographic composition was a close approximation of children residing in Hawaii (State of Hawaii Data Book, 1996).

The public school is a research arm associated with the University of Hawaii whose primary mission is to develop and test curricula suitable for children of differing abilities and sociodemographic backgrounds. Children are admitted to the school based on ethnicity, gender, parental socioeconomic and marital status, residence location, and academic achievement to approximate the State's census.

A private school was selected for participation to obtain a sample reflecting the relatively large number of children (i.e., 19%) attending private schools in the state (State of Hawaii Data Book, 1996). The school admits students from throughout the state, although the majority of children reside in the urban Honolulu area.

A letter, consent form, and demographic information form were mailed to parents of children attending both schools. The letter provided a basic description of the research project. The latter two forms were used to obtain written consent for children's participation and sociodemographic information (Duncan, 1961) concerning family members, respectively. Parental consent was obtained for all children in the study, reflecting response rates of 100% and 54% for the university-affiliated public school (participation in approved research studies is a required condition of admission) and private school, respectively. The ethnic composition of the sample was as follows: East Asian (35%), Part-Hawaiian (25%), Caucasian (9%), Southeast Asian (3%), Pacific Islander (1%) and Mixed (27%). Participants were labeled as "Part-Hawaiian" if any ethnicities within their ethnic background included Hawaiian. Participants were labeled "Mixed" if the ethnicities within their ethnic background could not be categorized by a single ethnic category. Institutional Review Board approval for the study was granted prior to data collection.

1.2. Measures

1.2.1. Teacher-rated attention problems

The Child Behavior Checklist (CBCL) Teacher Report Form (TRF) is a 118-item standardized teacher rating scale that includes eight empirically derived clinical syndrome scales, as well as composite indices of externalizing and internalizing broad-band syndromes, adaptive functioning, and academic performance. Items are rated on the following 3-point scale: (0) *not true*, (1) *somewhat or sometimes true*, or (2) *very true or often true*. The psychometric properties of the CBCL-TRF are well-established and detailed by Achenbach (1991). Teacher rating scales of attention problems have shown moderate to high criterion validity with direct observations of inattentive behavior (DuPaul, 1991). In particular, the CBCL-TRF attention problems scale score shows strong convergence with a diagnosis of ADHD (Biederman, Faraone, Doyle, & Lehman, 1993; Hudziak, Copeland, Stanger, & Wadsworth, 2004), direct observations of attention (Kofler et al., 2010) and laboratory measures of covert attentional processes (Rapport et al., 1999). The CBCL-TRF was selected intentionally as an ecologically valid assessment of attention problems due to its ability to assess primary indices of attention problems (e.g., 'cannot concentrate'), associated features (e.g., 'fidgets'), and secondary behaviors affected by attention problems (e.g., 'disturbs other pupils').

A manifest variable termed *Attention Problems* was used in the models and derived from the attention problems scale. Attention problems are viewed intentionally as a continuous dimension in accordance with the normative-developmental view of child psychopathology (Achenbach, 1990). In addition, evidence from genetic (Gjone, Stevenson, & Sundet, 1996; Levy, Hay, McStephen, & Wood, 1997) and latent profile analyses (Frazier, Youngstrom, & Naugle, 2007), as well as previous pathway

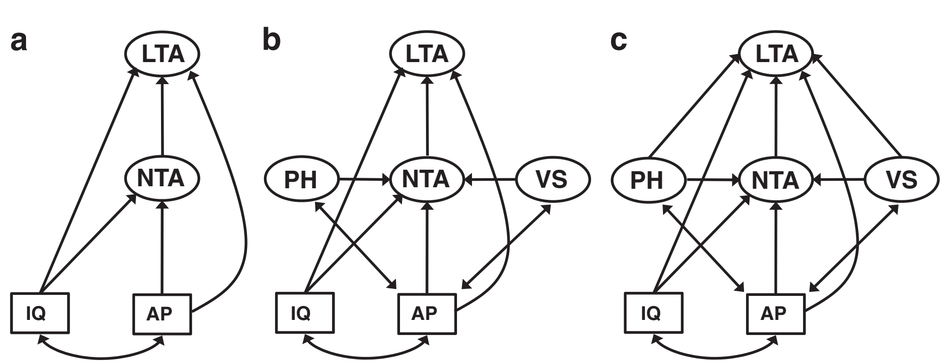

Fig. 1. Hypothesized conceptual models depicting the relationships among attention problems, IQ, near- and long-term scholastic achievement: (a) baseline model; (b) phonological/visuospatial short-term memory as mediators of near-term academic achievement; and (c) phonological/visuospatial short-term memory as mediators of near- and long-term academic achievement. AP = attention problems; IQ = intelligence quotient; NTA = near-term achievement; LTA = long-term achievement; PH = phonological short-term memory; VS = visuospatial short-term memory.

models of childhood disorders (e.g., Fergusson & Horwood, 1995; Fergusson et al., 1997) provide persuasive empirical arguments favoring a scalar view of attention problems. Raw scores (versus *T*-scores) were used in the analyses as recommended by Achenbach (1991) to account for the full range of variation in CBCL-TRF syndrome scale scores.

1.2.2. Near-term scholastic achievement

The Kaufman Test of Educational Achievement Brief Form (KTEA) is a standardized, individually administered battery that measures children's mathematics, reading, and spelling achievement between the ages of 6 and 18 years. Its psychometric properties and expected patterns of relationships with other measures of educational achievement are well established (Sattler, 2001). Subtest scores combine to yield a composite achievement score. A latent variable representing early scholastic achievement was derived using the KTEA composite score (termed *Near-term Achievement*) and corrected for measurement error by fixing its error term based on published test–retest reliability (Kaufman & Kaufman, 1998) as recommended by Kline (2005). For academic domain-specific models, latent variables representing early mathematics and reading achievement were derived using the separate mathematics and reading subtest scores and corrected for measurement error by fixing their error terms based on their published test–retest reliability coefficients.

1.2.3. Long-term scholastic achievement

The Stanford Achievement Test (Stanford Achievement Test, 1996) is a national, group-administered test for 3rd to 12th grade children used to assess long-term scholastic achievement across multiple domains. The SAT is administered by school personnel and is often used as a measure of scholastic achievement in studies examining the relationships between children's cognitive performance and scholastic functioning (e.g., Buckhalt, El-Sheikh, Keller, & Kelly, 2009). A latent variable termed *Long-term Achievement* was used in the models and derived from total reading, total math, and total language scale scores. For models examining academic domain-specific relations, the reading and mathematics subscales scores were used separately. Scale scores represent approximately equal units on a continuous scale, using numbers that range from 1 through 999, and are suitable for studying change in performance over time. SAT scores were collected between 3 and 4 years after the children were initially tested at the clinic.[2] Records were obtained from school personnel with the signed consent of the children's parents.

1.2.4. Phonological short-term memory

Paired Associate Learning Tasks (PAL-T) are related to classroom learning (Baddeley, Papagno, & Vallar, 1988; Stevenson, 1972) and academic achievement (Gathercole, Hitch, Service, & Martin, 1997). The task was selected because it is one of many tasks that place heavy demands on phonological storage and rehearsal, particularly when the paired associations involve learning arbitrary relationships (Baddeley et al., 1988; Douglas & Benezra, 1990; Douglas & Peters, 1979).

Children were required to identify letters of the alphabet and digits 0 through 9 to ensure letter and number recognition ability, respectively, prior to participating in a brief practice session. The task required children to learn arbitrary associations between letter bigrams (e.g., “GJ”) and a single numerical digit (e.g., “3”) in six blocks of five bigram-digit pairs. Bigram-digit stimuli were pre-programmed in a library file and presented on a color monitor. A single bigram was presented in the middle of the computer screen with its associate digit below. To ensure orientation and facilitate learning, children were required to use a track ball device to place the arrow on the digit and click it. Following presentation of five bigram-digit pairs to be learned, a test phase ensued and required children to correctly identify (using the track ball device) the digit (digits 0 through 9 are shown at the bottom of the screen) that was previously associated with the bigram. Incorrect responses during the test phase were followed by a computer tone and corrective feedback. Bigram–digit pairs were assessed three times in random order during the test phase. Following the test phase, a new block consisting of five bigram–digit associations was presented then tested for recall. The procedure continued until all six blocks of paired associations are presented, and assessed for recall. The two-week test–retest reliability of the PAL total score for a subsample of children ($n = 22$) was .79.

A higher order latent variable termed *Phonological Short-term Memory* was used in the models and derived by averaging the number of correct responses separately for the three, two-block combinations (i.e., blocks 1 and 2, 3 and 4, 5 and 6, respectively). The term phonological, rather than verbal, short-term memory was used to emphasize the former's inclusion of information that can be encoded auditorally or visually and orthographically converted into verbal-based code (Baddeley, 2007).

1.2.5. Visuospatial short-term memory

Visuospatial short-term memory was assessed using the Matching Unfamiliar Figures Task (MUFT). The MUFT is a visual match-to-sample paradigm employing complex geometric visual and spatial designs and is one of many tasks used to assess visuospatial short-term memory. Children were shown an abstract visual stimulus (target stimulus) surrounded by eight figures (i.e., seven nearly identical foils and one identical stimulus) and instructed to locate the one exact matching stimulus from the stimulus field (see Fig. 2). The figures were each 10 cm^2 in size and were evenly spaced within a 3×3 configuration such that the total computer screen space measured 41 cm by 30.5 cm. At the beginning of each trial, children used a track ball to position a small airplane icon inside the red box in the center of the screen to ensure orientation to the target stimuli. A single click anywhere within the center box illuminated the target stimulus and eight surrounding stimuli. The target stimulus was programmed to disappear after 10 s or after the child made an incorrect response, but could be re-illuminated by clicking the center stimulus box. An auditory tone was emitted following each correct response. A distinctly different tone followed incorrect responses. Children continued with each trial until they located the correct stimulus for each of the 20 visuospatial trials.

The size of (10 cm^2) and distance between the center of each stimulus were set so that two stimuli could not be processed simultaneously within a child's visual field (Holmes, Cohen, Haith, & Morrison, 1977). In addition, the presence of stimuli in children's central (foveal) fixation area effectively prevents identification and evaluation of peripheral stimuli (Holmes et al., 1977). The child must therefore engage in serial eye movements to focus on and evaluate foil stimuli while holding aspects of the complex target stimulus in memory, even when the target stimulus is present on the screen (for a review of working memory demands during visual search tasks requiring eye movement, see Woodman & Chun, 2006). Complex, abstract, and asymmetrical stimuli were used to maximize the demands placed on children's visual short-term memory (Dehn, 2008). Performance on each trial relies also on children's spatial memory of previously evaluated stimuli, given that only one aspect of a complex stimulus can be evaluated at a time (Houtkamp & Roelfsema, 2009). Visually distinct target and foil stimuli were used across trials to maximize memory demands (i.e., prevent the decreased reliance on working and short-term memory through automation that occurs when the same stimuli are used across trials; Baddeley, 2007; Woodman & Chun, 2006). The two-week test–retest reliability of the MUFT for a subsample of children ($n = 20$) was .81.

Total MUFT errors across the 20 trials served as the dependent variable for assessing short-term visuospatial memory ability. These values were

[2] The difference in time frame for collecting SAT data is related to when subsequent testing was conducted by schools, viz., 3rd, 6th, 9th, 11th, and 12th grades).

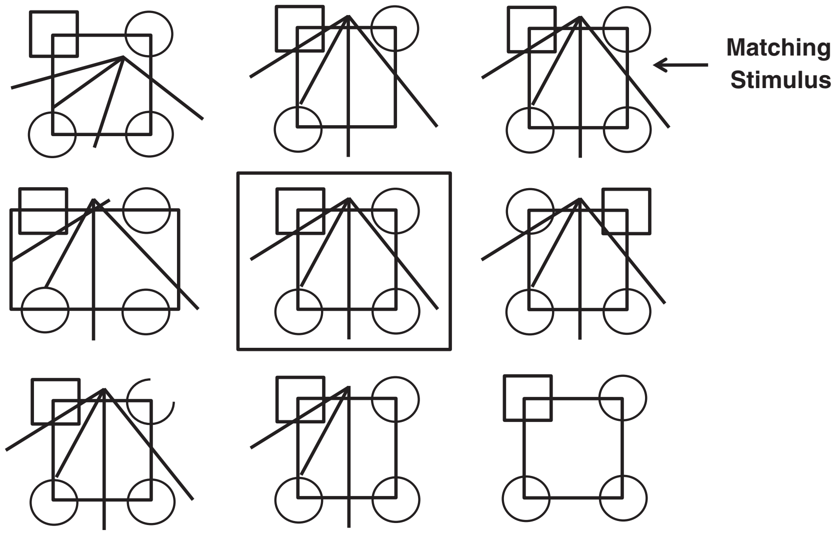

Fig. 2. Visual schematic of one trial taken from the Matching Unfamiliar Figures Test (MUFT). Central picture is the target stimulus to be matched to its exact replica among 7 foils. Note: Actual size of each stimulus is 10 cm^2.

reverse-scored to maintain numerical valence continuity across cognitive and academic variables. A latent variable termed *Visuospatial Short-term Memory* was used in the models and derived by dividing the task into three indicator blocks (7, 7, and 6 trials, respectively) and separately averaging the reverse-scored number of errors for each block as recommended by Kline (2005).

1.2.6. Intelligence

The Kaufman Brief Intelligence Test (K-BIT) consists of two subtests – Vocabulary and Matrices – that assess domains parallel to the crystallized-fluid (Horn, 1998) and verbal-performance (Wechsler, 1991) intellectual dichotomies. The two subtests can be combined to yield a composite IQ score. The psychometric properties of the K-BIT and expected patterns of relationships with other measures of intelligence are well established and detailed by Kaufman and Kaufman (1990). A manifest variable was created using the composite IQ score residualized for both phonological and visuospatial short-term memory performance owing to the overlap between phonological and visuospatial short-term memory ability and IQ (Engle et al., 1999).

1.2.7. Socioeconomic factors and age

Socioeconomic status (SES) was computed for each child's family using the Duncan Index (Duncan, 1961). SES and age were both partialled out of all variables in the models to control for their potentially confounding effects on modeled relationships. This was accomplished by residualizing the raw scores of variables before entry in the SEM models that were (a) significantly associated with age or SES, and (b) not previously age adjusted (see Table 1).

1.3. Procedures

Each child was evaluated once per week over a 2-week time period at a university-based child learning clinic. Children's intelligence (K-BIT), early scholastic achievement (KTEA), phonological (PAL-T) and visuospatial (MUFT) short-term memory abilities were assessed individually by trained graduate students for approximately 1.5 h during each of the two clinic visits. Ordering of testing was counterbalanced across sessions. Breaks (5–10 min) were scheduled between tests to minimize fatigue. Children were seated such that the computer monitor was approximately .5 m from the child with the center of the screen at eye level. An experimenter was present throughout all testing.

2. Results

The correlation matrix of study variables and standard deviations is shown in Table 1. Data from two children were excluded owing to missing MUFT scores. An additional six children were excluded after being identified as multivariate outliers based on Mahalanobis distances ($p<.001$), bringing the total N to 317. All variables were centered as recommended by Kline (2005).

A series of nested structural equation models (SEM) were constructed to examine the contribution of teacher-rated attention problems, intelligence, phonological and visuospatial short-term memory, and near-term scholastic achievement to later scholastic achievement. The hypotheses in this investigation were examined by imposing a hierarchical sequence of constraints on the values of the raw path coefficients in the model and assessing the impact of these constraints on model fit. Models were fit using AMOS version 18.0 with maximum-likelihood estimation (Arbuckle, 2009). The phonological and visuospatial short-term memory latent variables were allowed to covary in all models to control for expected shared method and setting variance. A chi-square difference test was used to contrast the nested models. This test evaluates whether increasing model complexity is justified by concurrent increases in model fit for the more complex relative to the less complex model. Overall goodness-of-fit for all models was evaluated using the following indices: Root Mean Squared Error of Approximation (RMSEA), Non-normed Fit Index (NNFI), Confirmatory Fit Index (CFI), and Goodness of Fit Index (GFI). RMSEA values $\leq.08$ and $\leq.05$ are indicative of adequate and good fit, respectively. For the NNFI, CFI and GFI, values $\geq.90$ and $\geq.95$ are indicative of adequate and good fit, respectively (Schweizer, 2010).

The measurement component of the models describes the relationships among the manifest variables (e.g., reading, math, and language) and their respective latent constructs (e.g., Long-term Scholastic Achievement). The factor loading of an indicator variable represents its correlation with the construct it is presumed to measure. The psychometric reliability of the indicator is equal to the proportion of its variance explained by the underlying construct. Thus, an indicator's reliability is determined by squaring its factor loading. The proportion of its variance that is unexplained (i.e., unique) is the complement of this value (i.e., 1 minus squared loading) and is displayed by the value labeled “E” in Figs. 3–5.

The measurement component of the model showed good internal consistency. The squared loadings for reading, math, and language

Table 1
Matrix of correlations and standard deviations of measures of attention problems, IQ, phonological short-term memory, visuospatial short-term memory, scholastic achievement, age, and SES.

Measures	Attention problems	Near-term scholastic achievement			Long-term scholastic achievement			Phonological short-term memory			Visuospatial short-term memory			Age	SES	IQ
		KTEA composite	KTEA math	KTEA reading	SAT math	SAT reading	SAT language	BL12	BL34	BL56	M1	M2	M3			
Attention problems	–															
KTEA composite	−.331**	–														
KTEA math	−.232**	.831**	–													
KTEA reading	−.295**	.797**	.497**	–												
SAT math	−.363**	.381**	.461**	.217**	–											
SAT reading	−.291**	.421**	.466**	.359**	.801**	–										
SAT language	−.418**	.508**	.470**	.381**	.737**	.777**	–									
BL12	−.197**	.123*	.258**	.043	.541**	.517**	.470**	–								
BL34	−.177**	.172**	.259**	.097	.545**	.555**	.499**	.662**	–							
BL56	−.149**	.210**	.317**	.107	.581**	.622**	.511**	.632**	.722**	–						
M1	−.082	.111*	.244**	.036	.373**	.368**	.337**	.321**	.388**	.365**	–					
M2	−.145**	.101	.206**	.027	.444**	.431**	.432**	.454**	.519**	.529**	.533**	–				
M3	−.139*	.085	.222**	.032	.444**	.464**	.433**	.453**	.455**	.495**	.575**	.573**	–			
Age	.054	−.265**	−.074	−.319**	.514**	.514**	.337**	.489**	.515**	.551**	.356**	.451**	.441**	–		
SES	−.123*	.249**	.180**	.274**	.075	.114*	.121*	−.005	−.017	.031	.010	.043	.058	−.132*	–	
IQ	−.273**	.721**	.675**	.615**	.375**	.450**	.448**	.209**	.231**	.239**	.220**	.192**	.214**	−.166**	.312**	–
SD	4.810	15.035	17.429	14.005	50.517	44.435	37.676	2.755	3.114	3.474	2.950	3.798	4.556	2.377	18.451	11.927

Note: ADHD = CBCL-TRF attention problems raw score; BL = Paired associates learning for blocks 1–2, 3–4, or 5–6; M = Matching unfamiliar figures test trials 1–7 (M1), 8–14 (M2), and 15–20 (M3); IQ = Kaufman Brief Intelligence Test; KTEA = Kaufman Test of Academic Achievement—Brief Form; SAT = Stanford Achievement Test; SES = socioeconomic status.

** $p < .01$.

* $p < .05$.

SAT composite scores were .80, .75, and .75, respectively. Phonological (Paired Associates Learning blocks 1 and 2, 3 and 4, 5 and 6) and visuospatial (blocks 1, 2, and 3) short-term memory indicator loadings showed a similar pattern of internal consistency (ranges = .67 to .79 and .70 to .79, respectively).

For all models, β-weights and correlations were significant at $p < .001$ unless noted. Fit indices, χ^2 difference tests, and near- and long-term R^2 values for all models are shown in Table 2.

2.1. Composite achievement

2.1.1. Model 1

The initial model established the relationship among attention problems, IQ, and near- and long-term scholastic achievement. This model (Fig. 3a) was based on the premise that later scholastic achievement is a function of the early influence of attention problems and IQ – but not phonological and visuospatial short-term memory – and that near-term scholastic achievement mediates these relationships (Rabiner et al., 2000). The model was estimated by allowing all hypothesized pathways to be freely estimated with the exception of those involving phonological and visuospatial short-term memory, which were constrained to equal zero due to their hypothesized non-contributory influence in the model.[3]

Inspection of the pathways in Fig. 3a revealed significant relationships between attention problems and near- (β = −.18) and long-term (β = −.26) scholastic achievement after accounting for attention problems' negative association with intelligence ($r = -.20$). Intelligence showed a strong association with near-term (β = .64) but not long-term scholastic achievement ($p = .19$) after accounting for its shared variance with attention problems. Finally, near-term scholastic achievement showed moderately strong continuity (β = .46) with long-term academic achievement after accounting for IQ and attention problems. The disturbance terms (D) can be squared and subtracted from 1 (i.e., $1 - D^2$) to determine the percentage of variance accounted for in near- (i.e., 48%) and long-term (i.e., 30%) scholastic outcomes. The fit indices, however, were slightly below recommended values (see Table 2).

2.1.2. Model 2

The expanded model tested the plausibility that phonological and visuospatial short-term memory attenuate the relationship between attention problems and long-term scholastic achievement through their collective impact on near-term achievement (Engle et al., 1999). The model also tested whether these variables attenuate the direct relationship of attention problems on near-term scholastic achievement by evaluating the degree to which the strength of this relationship was diminished relative to Model 1. The model was estimated by constraining the two paths between phonological and visuospatial short-term memory and long-term scholastic achievement to zero, and allowing all other pathways between variables to be estimated freely (Fig. 3b).

The chi-square difference test between Models 1 and 2 revealed that allowing phonological and visuospatial short-term memory to predict near-term achievement improved model fit significantly (see Table 2). Overall model fit was determined to be marginally acceptable based on fit indices slightly above (CFI, GFI) and slightly outside established cutoff values (NNFI, RMSEA). Inspection of model pathways revealed significant negative relationships between attention problems and phonological ($r = -.26$) and visuospatial short-term memory ($r = -.17$) after accounting for its covariation with intelligence.

[3] This model was recomputed by deleting the phonological and visuospatial short-term memory variables to match the schematic shown in Fig. 1a. All parameters and R^2 values were identical to those reported for Model 1. In addition, model fit was determined to be similar based on comparison of fit indices. Phonological and visuospatial short-term memory were thus included in all models to enable nested model comparisons (Kline, 2005).

Intelligence, in turn, showed strong continuity with near-term (β = .60) but not long-term scholastic achievement (p = .18). Phonological short-term memory contributed to near-term scholastic achievement (β = .31) and partly attenuated the relationship between attention problems and near-term scholastic achievement (Δβ = .07).[4] Visuospatial short-term memory did not predict near-term achievement (p = .55). The magnitude of the association between attention problems and long-term scholastic achievement remained significant and unchanged (β = −.26). Finally, the continuity between near-term and long-term scholastic achievement remained virtually unchanged (β = .45) despite the significant contribution of phonological short-term memory to near-term scholastic achievement. Percentage of variance accounted increased marginally ($\Delta R^2 = .05$) for near-term but was similar for long-term achievement relative to Model 1 (i.e., 29%; $\Delta R^2 = -.01$).

2.1.3. Model 3

The final model tested the hypothesis that phonological and visuospatial short-term memory attenuate the relationship between attention problems and long-term scholastic achievement through their direct contributions to long-term scholastic outcomes. The model also tested whether these variables attenuate the continuity between near- and long-term achievement by evaluating the magnitude of change in this relationship. The model was estimated by relieving all constraints and allowing all paths between model variables to be estimated freely (Fig. 3c).

The chi-square difference test between Models 2 and 3 revealed significantly improved model fit (see Table 2). All fit indices fell at or above recommended cutoff values, indicating excellent model fit. Inspection of pathways revealed that visuospatial (β = .54) but not phonological (p = .34) short-term memory showed strong continuity with long-term scholastic achievement. Despite visuospatial short-term memory's large impact on long-term achievement, the direct effect of attention problems on long-term scholastic achievement (β = −.18) was only partially attenuated (Δβ = .08). Intelligence continued to impact near-term (β = .60) but not long-term (p = .96) scholastic achievement.[5] Furthermore, the magnitude of the continuity between near- and long-term achievement was partially attenuated by visuospatial short-term memory (Δβ = .13). The percentage of explained variance increased substantially ($\Delta R^2 = .30$) for long-term achievement but did not change for near-term achievement relative to Model 2 as expected.

2.2. Alternate composite achievement models

Two additional sets of models were created to examine (a) potential gender differences, and (b) the interrelationship among teacher-reported attention problems and phonological/visuospatial short-term memory.

2.2.1. Gender invariance

A multi-group model was created to test for gender invariance. Results revealed that model fit was not improved significantly by allowing pathways to be estimated freely for boys and girls separately relative to constraining these pathways to be equal ($\Delta\chi^2$ (6) = 12.39, p > .05). This finding suggests that the results of the current study can be interpreted similarly for boys and girls.

2.2.2. Competing causal structures

Two alternative causal models were created to determine whether a directional model would better describe the relationship between attention ratings and short-term memory (i.e., 'attention → phonological and visuospatial short-term memory' vs. 'phonological and visuospatial short-term memory → attention') relative to modeling these variables as intercorrelated as shown in Fig. 3. Two fit indices that can be used to compare non-nested models were examined: Akaikei's Information Criteria (AIC), and the Expected Cross-Validation Index (ECVI), with smaller values indicating better fit (Byrne, 2010). Across the 3 models ('attention/short-term memory covariation', 'attention predicting short-term memory', and 'short-term memory predicting attention'), the AIC (167, 161, and 167) and ECVI (.53 [90% CI_{ECVI} = .45 to .63], .51 [90% CI_{ECVI} = .44 to .61], and .53 [90% CI_{ECVI} = .45 to .63]) values were approximately equivalent across models, suggesting model equivalence. Further evidence supporting the covariation model was found by examining standardized β-weight magnitudes across the two alternate causal models. Confidence interval analysis revealed that attention predicted both short-term memory variables as well as both short-term memory variables predicted attention (Cumming & Finch, 2005; rule 7). Interpretations were therefore based on the covariation model presented above and shown in Fig. 3.

2.3. Domain-specific achievement

A final series of structural equation models were created to evaluate whether the results reported for overall scholastic achievement vary when examining reading and math achievement separately. The models were identical to the composite achievement models with respect to the sequence of applied constraints.

2.3.1. Reading achievement

Relieving constraints within Models 2 and 3 significantly improved model fit, with only Model 3 achieving all fit indices within recommended parameters (see Table 2). The results revealed a pattern of effects comparable to the final composite achievement model (i.e., Model 3) with one exception. Visuospatial short-term memory predicted long-term reading achievement (β = .51) independent of the continuity between near-term and long-term reading achievement (Fig. 4).

2.3.2. Math achievement

Relieving constraints within Models 2 and 3 significantly improved model fit, with only Model 3 achieving all fit indices within recommended parameters (see Table 2). The results revealed a somewhat comparable pattern of relationships relative to the final composite achievement model (i.e., Model 3) with two noteworthy exceptions. Visuospatial short-term memory was significantly related to near-term math achievement (β = .18), and the collective contribution of phonological and visuospatial short-term memory fully attenuated the relationship between attention problems and near-term math achievement (see Fig. 5).

3. Discussion

The present study used a series of nested structural equation models to test hypotheses concerning the contributing effects of children's phonological and visuospatial short-term memory and teacher-rated attention on near- and long-term scholastic achievement. Results of the initial composite model were consistent with previous studies demonstrating that teacher-reported attention problems are associated negatively with near- (Frick et al., 1991) and long-term (Barkley et al., 2006; Fergusson et al., 1997) scholastic achievement, even after controlling for intelligence, age, and socioeconomic status. The full composite model, however, indicated that children's phonological and visuospatial short-

[4] Partial attenuation was tested in this and all subsequent models by fitting an alternate model in which the direct pathway was constrained to equal the parameter found in the previous model, with a significant degradation in model fit indicating partial attenuation. For example, constraining the Model 2 attention problems–NTA pathway to −.18 (its value in Model 1) resulted in a significantly worse model fit ($\Delta\chi^2$ (1) = 12.00, p < .001), indicating a significant change in parameter magnitude. Inspection of the β-weights for Model 1 (−.18) and Model 2 (−.11) revealed that this change reflected a decrease in β-weight magnitude.

[5] The same series of models were repeated to determine whether the nonsignificant IQ–LTA relationship was due to our use of a residualized IQ variable (see Method). The pattern of results, however, remained unchanged when overlapping variance with phonological and visuospatial short-term memory was not removed from intelligence. All paths from IQ to long-term achievement were nonsignificant for the composite, reading, and math achievement models (all p > .05).

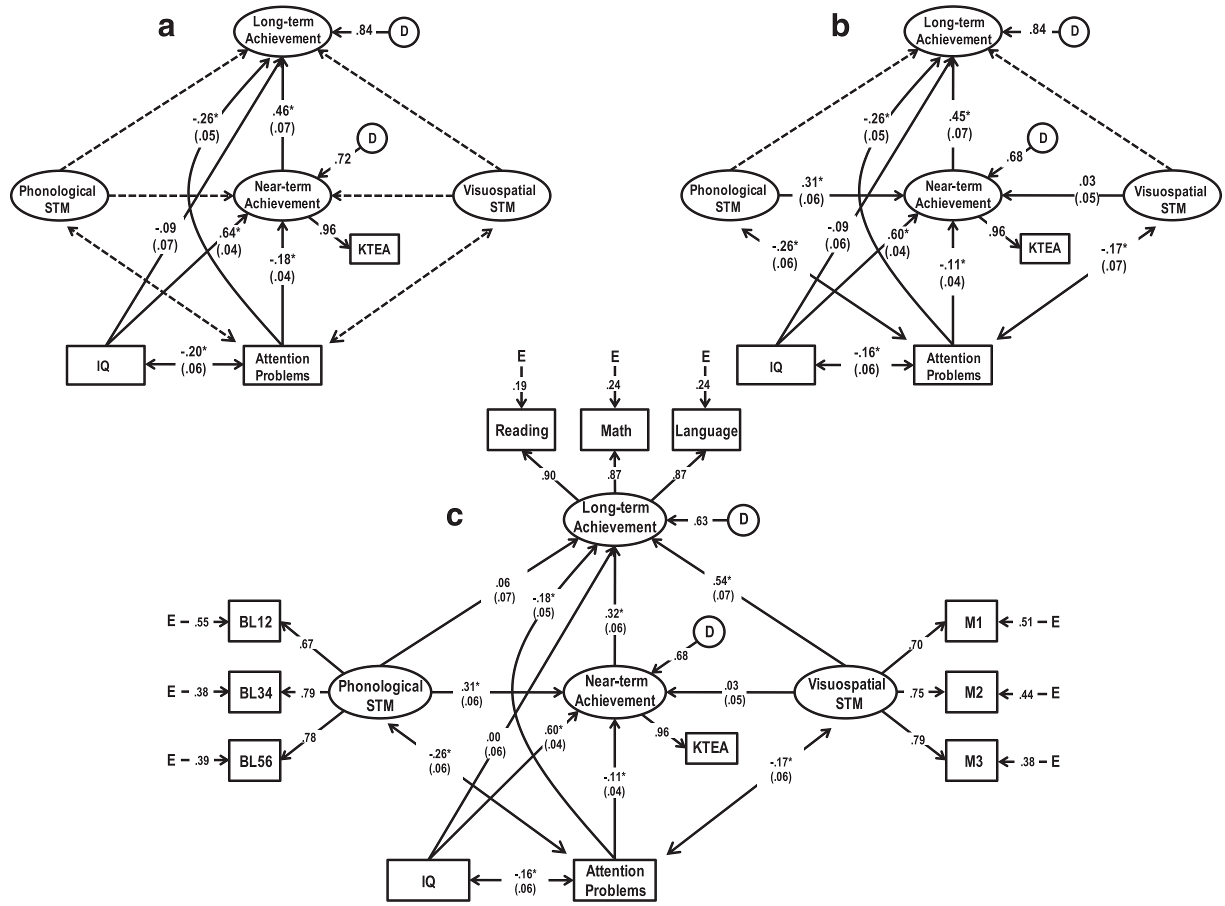

Fig. 3. Structural equation models predicting composite long-term scholastic achievement. Factor loadings and error terms (E) associated with latent variables (Long-term Achievement, Phonological Short-term Memory, Visuospatial Short-term Memory) are identical for all three models, but shown only for Model c for visual clarity. Values reflect standardized β coefficients (standard error in parentheses). Dashed lines represent pathways constrained to zero. BL = Paired Associates learning for blocks 1–2, 3–4, or 5–6; D = disturbance term. IQ = residualized intelligence variable with overlapping variance with memory variables removed. M = Matching Unfamiliar Figures Test trials 1–7 (M1), 8–14 (M2), and 15–20 (M3). R^2 values in text may differ slightly from the R^2 calculated using disturbance terms due to rounding. Correlation between the phonological and visuospatial short-term memory factors ($r = .48$) was omitted from Models 2 and 3 for visual clarity. *$p < .05$.

term memory abilities differentially attenuated the continuity between teacher-rated attention problems and both near- and long-term scholastic achievement. Specifically, phonological short-term memory partially attenuated the direct effects of attention problem ratings on near-term achievement, whereas visuospatial short-term memory partially attenuated the direct effects of attention problem ratings and near-term achievement on long-term achievement.

The contribution of phonological short-term memory to near- but not long-term achievement in all models is consistent with previous findings documenting the contribution of phonological abilities to academic achievement (Gathercole, Brown, & Pickering, 2003; Thorell, 2007). The contribution of visuospatial short-term memory to long-term but not near-term achievement, in contrast, replicates developmental patterns between cognition and scholastic achievement reported in the literature (Meyer, Salimpoor, Wu, Geary, & Menon, 2010), and provides context for understanding the divergent associations. Specifically, visuospatial memory underlies complex fluid reasoning skills (Kane et al., 2004), and its association with later but not near-term scholastic achievement may reflect its increasing convergence with working memory abilities with age and increasing demands on reasoning and comprehension as children advance in school (Tillman, 2010). For example, phonological abilities play an important role in early computation and number fact retrieval performance, whereas visuospatial abilities contribute to more advanced mathematic skills such as comprehension performance (Meyer et al., 2010). Collectively, accounting for phonological and visuospatial short-term memory doubled the explained variance in long-term achievement (from 30% to 60%), and underscores the important contribution of these abilities to the development of children's academic competencies.

The unique relationships among intelligence, short-term memory, and teacher-reported attention problems highlight the complex interactions among these constructs, and extend the findings of previous investigations examining near- and long-term predictors of children's achievement. Both phonological short-term memory and intelligence, for example, exerted a moderate to robust effect on children's early scholastic achievement, but provided no incremental benefit beyond this time. The impact of intelligence on early scholastic achievement is consistent with findings reported in other investigations (Alloway, 2009; Mayes, Calhoun, Bixler, & Zimmerman, 2009; Rabiner et al., 2000); however, its failure to contribute to children's scholastic achievement in later years is inconsistent with some previous longitudinal models (e.g., Rabiner et al., 2000; Rapport et al., 1999). The discrepancy in findings may reflect our statistical control for common variance between phonological/visuospatial short-term memory and intelligence in the three models. A post-hoc examination of the models without controlling for common variance, however, yielded nearly identical results. A more convincing explanation for the discrepant findings is the absence of near-term achievement measures in some

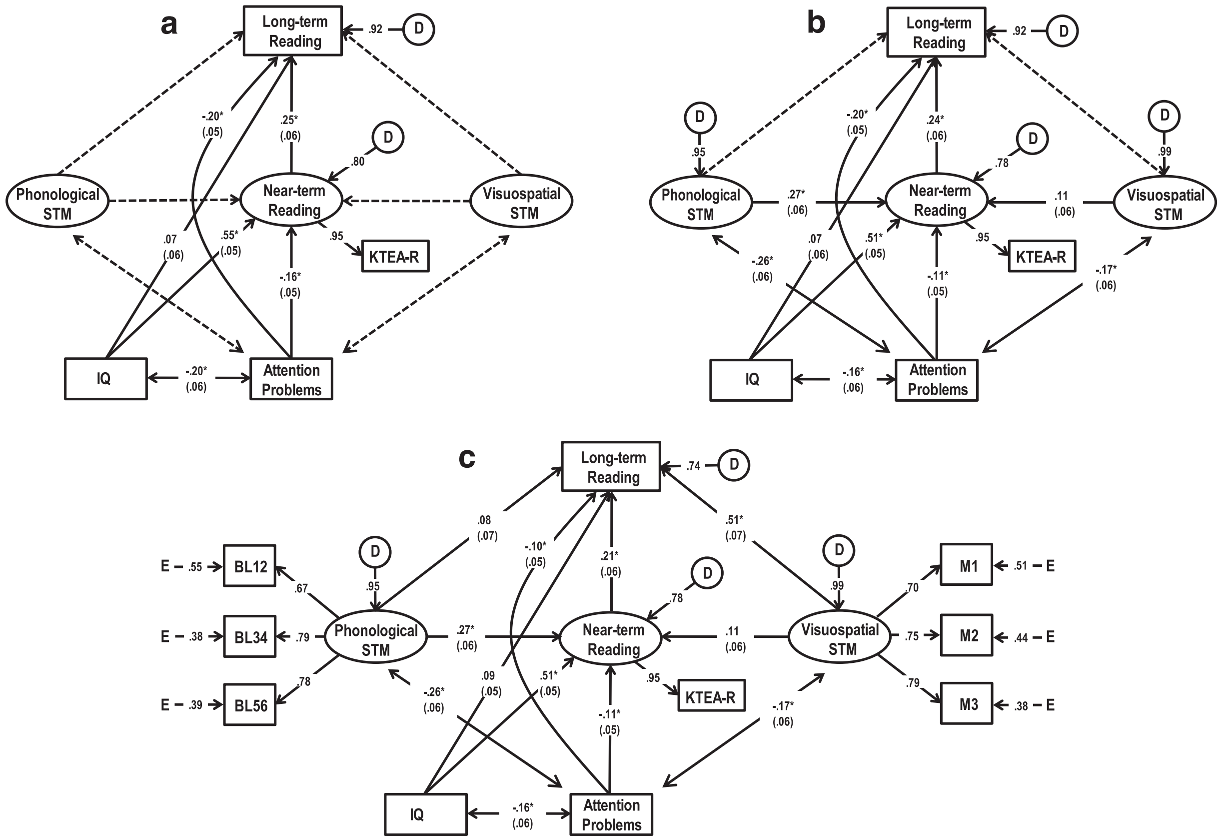

Fig. 4. Structural equation models predicting long-term reading achievement. Factor loadings and error terms (E) associated with latent variables (Phonological Short-term Memory, Visuospatial Short-term Memory) are identical for all three models, but shown only for Model c for visual clarity. Values reflect standardized β coefficients (standard error in parentheses). Dashed lines represent pathways constrained to zero. BL = Paired Associates learning for blocks 1–2, 3–4, or 5–6; D = disturbance term; KTEA-R = Kaufman Test of Educational Achievement-Reading Composite; IQ = residualized intelligence variable with overlapping variance with memory variables removed; M = Matching Unfamiliar Figures Test trials 1–7 (M1), 8–14 (M2), and 15–20 (M3). R^2 values in text may differ slightly from the R^2 calculated using disturbance terms due to rounding. Correlation between the phonological and visuospatial short-term memory factors (r = .48) was omitted from Models 2 and 3 for visual clarity. *p < .05.

previous longitudinal models, and the likelihood that intelligence provides minimal or no incremental contribution to later academic achievement after accounting for its initial impact (r = .23 to .51) on early achievement (Alloway, 2009; Cain et al., 2004; Mayes et al., 2009; Rabiner et al., 2000).

The unique relationship between attention problems and scholastic achievement was also of interest. Longitudinal studies have conventionally found that the association between teacher-rated attention problems and scholastic achievement is influenced heavily by early academic learning (Rabiner et al., 2000; Volpe et al., 2006), and fully mediated by cognitive and behavioral factors (Rapport et al., 1999). Our findings, in contrast, indicate that attention problem ratings were associated negatively with long-term scholastic achievement and are attenuated only partially by near-term achievement and visuospatial short-term memory. The disparity in findings likely reflects the inclusion of classroom performance mediators in previous models – viz., academic success, performance and efficiency – that contribute uniquely to children's long-term achievement over and above their relationship to near-term achievement. These variables may reflect dispositional (motivation, persistence) and classroom situational factors that contribute to children's learning in educational settings (cf. Volpe et al., 2006) and merit consideration in future studies of academic outcomes.

Domain-specific models revealed a pattern similar to the composite achievement model with a few noteworthy exceptions. Specifically, phonological but not visuospatial short-term memory significantly attenuated the relationship between attention problem ratings and near-term reading achievement, with attention problems continuing to predict long-term reading achievement. The findings for the math achievement model, in contrast, revealed that visuospatial and phonological short-term memory together fully attenuated the effect of attention problem ratings on near-term math achievement, although attention problems continued to predict long-term math achievement. In addition, visuospatial short-term memory impacted both near- and long-term math achievement and partially attenuated the near- to long-term math achievement relationship.

The value of the present study was to identify potential cognitive mediators that account for the impact of teacher-reported attention problems on the developmental sequence of scholastic achievement. Several caveats, however, merit consideration when interpreting the current findings. Generalization from community samples to children with functionally impairing attention deficits (e.g., ADHD) is always limited to some extent; however, extant evidence suggests that scholastic achievement predictors show only minor differences between typically developing children and children with ADHD (DuPaul et al., 2004). Our sample also relied exclusively on empirically derived teacher ratings of attention problems, which have high ecological validity but also contain items reflecting behavioral correlates and outcomes presumed to be manifestations of deficient covert attentional processes. The magnitude of the interrelationships among attention, memory, and achievement may have been greater if laboratory measures of multiple covert attentional processes (e.g., focused, divided, and/or selective attention) had been used to index children's attention problems. In addition, the sample was limited to a 4-year follow-up evaluation period and did not include measures of other academic domains (e.g., science). Nevertheless, our results are highly consistent with earlier studies examining the developmental trajectory of attention problems, IQ, and later scholastic achievement, and provide a strong fit between the hypothesized

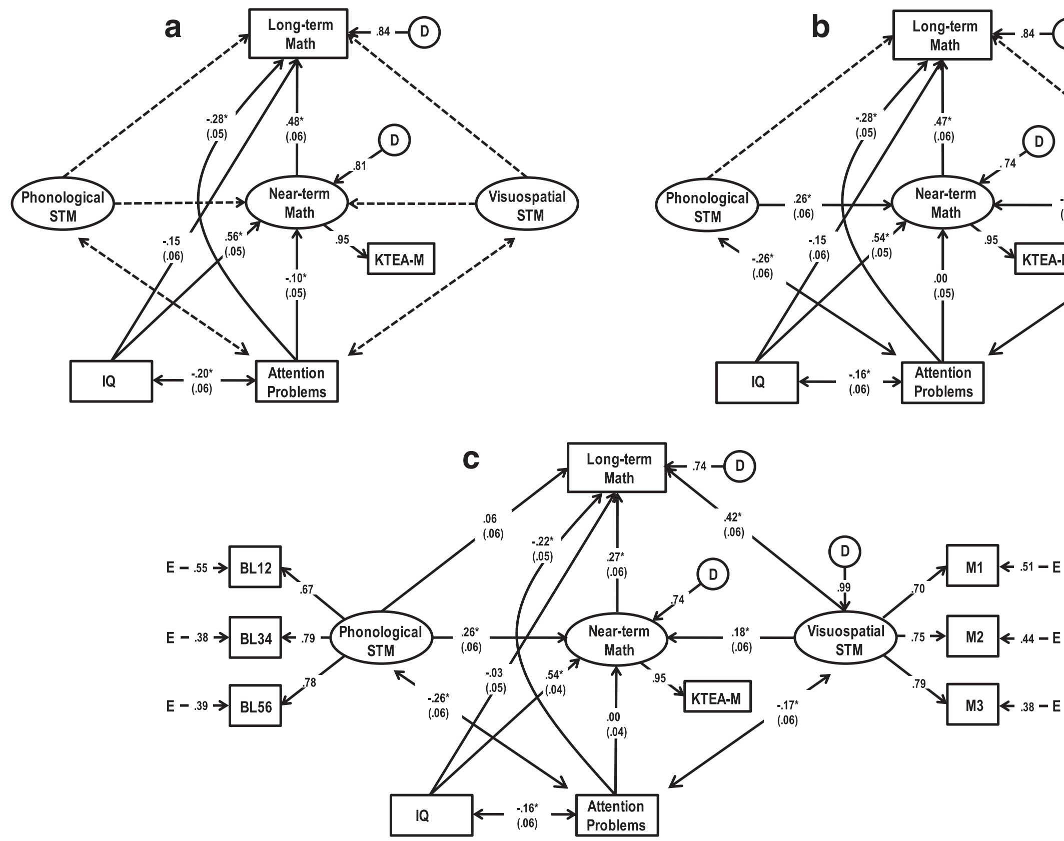

Fig. 5. Structural equation models predicting long-term math achievement. Factor loadings and error terms (E) associated with latent variables (Phonological Short-term Memory, Visuospatial Short-term Memory) are identical for all three models, but shown only for Model c for visual clarify. Values reflect standardized β coefficients (standard error in parentheses). Dashed lines represent pathways constrained to zero. BL = Paired Associates learning for blocks 1–2, 3–4, or 5–6; D = disturbance term; KTEA-M = Kaufman Test of Educational Achievement-Math Composite; IQ = residualized intelligence variable with overlapping variance with memory variables removed; M = Matching Unfamiliar Figures Test trials 1–7 (M1), 8–14 (M2), and 15–20 (M3). R^2 values in text may differ slightly from the R^2 calculated using disturbance terms due to rounding. Correlation between the phonological and visuospatial short-term memory factors ($r = .48$) was omitted from Models 2 and 3 for visual clarity. $^*p < .05$.

model and data while controlling for measurement error. Finally, even though visuospatial short-term memory and teacher-rated attention problems predict and temporally precede long-term achievement, adding additional variables to the current model (e.g., working memory, classroom instruction, parental involvement) may incrementally explain additional variance in long-term academic achievement.

Table 2
Summary of model fit statistics for scholastic domain-specific models.

Model	*df*	$\Delta\chi^2$	CFI	NNFI	GFI	RMSEA (90% CI)	NTA R^2	LTA R^2
Composite								
SEM 1	32	–	.88	.84	.89	.12 (.10 to .13)	.48	.30
SEM 2	28	60.07***	.91	.87	.91	.11 (.09 to .12)	.53	.29
SEM 3	26	115.03***	.97	.96	.96	.06 (.04 to .08)	.53	.60
Reading								
SEM 1	32	–	.84	.76	.90	.12 (.11 to.14)	.36	.16
SEM 2	28	41.53***	.88	.81	.93	.12 (.10 to.13)	.38	.16
SEM 3	26	104.23***	.99	.97	.98	.04 (.01 to.07)	.39	.45
Mathematics								
SEM 1	32	–	.84	.78	.91	.13 (.11 to.14)	.35	.29
SEM 2	28	81.32***	.92	.87	.94	.10 (.08 to.12)	.46	.29
SEM 3	26	65.32***	.98	.97	.97	.05 (.02 to.07)	.46	.46

Note: CFI = Confirmatory Fit Index; df = degrees of freedom; GFI = Goodness of Fit Index; NNFI = Bentler–Bonnett Nonnormed Fit Index; NTA = near-term scholastic achievement; LTA = long-term scholastic achievement; RMSEA = Root Mean Squared Error of Approximation; SEM = structural equation model.
*** $p \leq .001$.

Collectively, our results indicate that attention problems observed by teachers are associated negatively with children's scholastic achievement, both initially and over time. This influence is attenuated partially by the diminished phonological and visuospatial short-term memory abilities that frequently underlie the observed behavioral manifestations of classroom attention problems in children (Garon et al., 2008), with the former contributing more heavily to near-term achievement, and the latter to long-term achievement. Based on these findings, we would expect interventions targeting children's short-term storage capacity to result in concurrent improvements in children's ability to pay attention in the classroom and in their academic achievement. This expectation is supported to a limited degree by recently developed cognitive interventions aimed at improving short-term memory in children with attention problems. For example, improving phonological and visuospatial short-term storage capacity is associated with improved performance on some non-trained tasks and modest decreases in parent-reported attention problems, but fail to result in significant improvements in academic functioning or attentive behavior at school (Shipstead, Redick, & Engle, 2010). The unexplained variance in near- and long-term achievement in the current study is consistent with these limitations, and suggests that concurrent attentional training may be needed to augment short-term memory training to the extent that attentional resources are necessary for the higher-order cognitive processes critical to academic functioning (viz., working memory, inhibition, set shifting) (Garon et al., 2008). Finally, the relatively weak association between teacher-rated attention problems and academic achievement after accounting for differences in children's phonological and visuospatial short-term memory suggests that brief, standardized cognitive batteries of these and additional measures (e.g., working memory) may prove more useful for identifying children at risk for both near- and long-term scholastic problems relative to teacher ratings (Gathercole et al., 2003).

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