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A longitudinal study of potential mediators of the relationship between inattention and academic achievement in a community sample of elementary school children

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Introduction: Behavioral attention, working memory (WM), and academic achievement share significant variance, but the direction of relationships across development are unknown. The aim of the present study was to determine whether WM mediates the pathway between inattentive behaviour and subsequent academic outcomes. **Methods:** 204 students from grades 1-4 (50% female) were recruited from elementary schools. Participants received assessments of WM and achievement at baseline and one year later. Teachers completed the SWAN behaviour rating scale both years. Mediation analysis with PROCESS (Hayes, 2013) was used to determine mediation pathways. **Results:** Inattention indirectly and directly influenced math addition, subtraction and calculation scores through its effect on visual-spatial WM. Children who displayed better attention had higher WM scores, and children with higher WM scores had stronger scores on math outcomes. Bias-corrected bootstrap confidence intervals for the indirect effects were entirely below zero for three out of four math outcomes. WM did not mediate the direct relationship between inattention and math and reading fluency scores. **Discussion:** Findings identify inattention and WM as longitudinal predictors for math addition, subtraction and calculation outcomes one year later, with visual-spatial WM as significant mediator. Results highlight the close relationship between inattention and WM and their importance in the development of math skills.

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A strong body of literature has provided evidence of a link between classroom inattention and academic achievement (for a review, see Polderman, Boomsma, Bartels, Verhulst, & Huizink, 2010). Although Polderman and colleagues included the behavioral dimension of hyperactivity in their review, it is the behavioral dimension of inattention that has consistently been found to be a risk factor for poor academic achievement across development (for example, Garner et al., 2014; Pingault et al., 2011). Inattention is an independent predictor of performance in multiple achievement domains that are important throughout the elementary school years, including arithmetic fluency (Fuchs et al., 2006; Lewandowski, Lovett, Parolin, Gordon, & Codding, 2007), arithmetic word problems (Fuchs et al., 2006; Swanson, 2011) and algorithmic computation (Fuchs et al., 2006; Li & Geary, 2013; Raghubar et al., 2009), as well as for composites of arithmetic fluency and algorithmic computation (Fitzpatrick & Pagani, 2013; Gold et al., 2013). These three math domains are distinguishable (Fuchs et al., 2006). Arithmetic fluency is defined as single digit math fact computation with a timed component, where students are expected to quickly and accurately solve math fact problems. As children become efficient counters, associations between pairs of numbers become consolidated in long-term memory, therefore relying more on retrieval memory and putting less burden on WM for answering math fact questions (Geary, Brown, & Samaranayake, 1991). Petrill and colleagues (2012) found that arithmetic fluency is genetically distinct from other non-timed measures of math calculation, problem solving and number concepts (Petrill et al., 2012). Arithmetic fluency plays a role in the development of algorithmic computation, which is defined by Fuchs et al. (2006 p.30) as "adding, subtracting, multiplying or dividing whole numbers, decimals or factions using algorithms and arithmetic." This more complex form of math moves beyond single digit to multi-digit computation and necessitates the ability to follow procedural steps as well as reliance on math fact retrieval. Math word problems, in which arithmetic problem solving questions are written (or read) out in sentences, requires reading skills as well as both math fact knowledge and the ability to follow complex procedures and hold and connect pieces of information in WM.

Reading fluency is another important domain of achievement during the elementary school years, as it is a consistent predictor of later reading comprehension skills (Pearce & Gayle, 2009; Roehrig, Petscher, Nettles, Hudson, & Torgesen, 2008). The ability to read fluently in the early grades is also predictive of high-stakes achievement test scores in elementary and middle school, and continues to predict reading comprehension scores into adulthood (Baker et al., 2014; Tighe & Schatschneider, 2014). There is some evidence that reading fluency is linked to attention, in that inattention is a predictor of poor reading fluency outcomes in typical developing school children (Pham, 2013). One study using a community sample of elementary school children found that mid-term teacher-rated inattention predicted reading fluency at the end of the same year, although it did not predict basic reading (word reading and decoding ability) (Grills-Taquechel, Fletcher, Vaughn, Denton, & Taylor, 2013). Studies with clinical groups have also found that children with Attention-deficit/hyperactivity disorder (ADHD) have lower reading fluency outcomes than their peers (Jacobson et al., 2011; Willcutt, Pennington, Olson, & DeFries, 2007).

The mechanisms of association between inattention and math and reading outcomes are not yet delineated. However, the cognitive factor of working memory (WM) has been implicated in academic achievement and is strongly related to inattention, and thus presents as a possible mediating variable within this relationship (Fuchs et al., 2005; Martinussen & Tannock, 2006; Swanson & Beebe-Frankenberger, 2004). One 'map' to describe a theory of the WM domain, is that WM is a limited-capacity system that temporarily holds and manipulates information. This model includes separate storage modules for auditory-verbal and visual-spatial information, and a central executive component that interfaces with other systems such as long term memory and perceptual systems (Baddeley, 2012). Children with poor WM ability demonstrate impaired academic performance, including impaired performance on tests of overall reading and math, and reading fluency (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Bental & Tirosh, 2007; Gathercole & Pickering, 2000; Jacobson et al., 2011). These same children are rated by teachers as having more problems with inattention and distractibility (Alloway et al., 2009). Working memory deficits often co-occur with attention difficulties, both in those with disorders of attention and across the spectrum of typical behavior (Gathercole & Pickering, 2000; Martinussen & Tannock, 2006; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Moreover, when examined across one school year, inattention, WM and academic fluency were found to share a significant amount of variance in a community sample of elementary school children (Gray, Rogers, Martinussen, & Tannock, submitted manuscript), supporting the hypothesis that these three factors comprise a triad of impairment during the elementary years and into high-school (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011).

Currently there is no robust evidence regarding the direction of the relationships within this triad of impairment, and causal pathways are unknown. One study found that trajectories of ADHD behavior could be established based on cognitive features at 15 and 24 months, and that those with more severe ADHD symptoms in grade 3 did show some behavioral differences prior to starting school. The researchers found that early signs of both behavioral and cognitive difficulties were associated with a stable trajectory of poor academic achievement into grade 3 (Arnett, Macdonald, & Pennington, 2013). Although this study provides evidence as to the early emergence of both behavioral and cognitive difficulties, and their association with low academic achievement, a grouping of cognitive features based on general intelligence and grouping inattention with an 'externalizing behavior' composite does not allow for looking at domains of specific relevance to academic achievement, such as WM and the spectrum of inattention. Another study, examining a sample of term and pre-term children, found that a measure of executive function (EF) (including visual-spatial WM) did not contribute unique variance to teacher-rated inattention scores in preschool, but visual-spatial span did contribute unique variance to these scores in primary school (Aarnoudse-Moens, Weisglas-Kuperus, Duivenvoorden, van Goudoever, & Oosterlaan, 2013). These studies indicate changes in the relationship between teacher-rated attention and WM throughout early development. Other studies have investigated possible mediators that provide some account of the consistent relationship between inattention and academic achievement. In a sample of high school students presenting with clinical and sub-clinical levels of ADHD symptoms, WM was found to be a mediator of the relationship between inattention and reading and math composite scores (Rogers et al., 2011). Thorell (2007), examined WM in a mediating role within an EF composite score. They found that this EF score mediated the relationship between inattention and pre-academic skills in kindergarten-aged children (Thorell, 2007).

The current study sought to extend these studies to a community sample of elementary school children and to further delineate the nature of the relationship between classroom inattention, WM domains and academic achievement through using a longitudinal mediation design.

Differential influences of visual-spatial and auditory-verbal WM are of interest, given previous research that implicates visual-spatial WM as an important factor in math achievement in elementary and high school, and previous findings of differential relationships between WM domain and achievement domain (Li & Geary, 2013; Rogers et al., 2011). Based on the described previous studies as well as on examination of this sample within a 1 year time frame (Gray, Rogers, Martinussen, & Tannock, submitted manuscript), it is hypothesized that there will be a direct relationship between classroom inattention at one point in time and both math and reading outcomes one year later. Additional hypothesizes posit that inattention will indirectly influence math outcomes through visual-spatial and auditory-verbal WM, and indirectly influence reading outcomes through auditory-verbal WM.

Materials and Methods

Participants

Participants were 204 elementary school-aged children (49% female) in grades 1-4 (ages 5-9, M = 7.67, SD = 0.91), who were drawn from a larger sample of 524 students, as described below. Students and their teachers and parents were recruited from a large suburban and rural school district in Southern Ontario, Canada. The 7 participating schools (20% of the 33 schools in the district) were stratified across socio-economic groups. Since detailed data on the sample have been previously described (Gray, Rogers, Martinussen & Tannock, submitted manuscript), here, we provide only a summary of the sample characteristics. The majority were Caucasian (80.6%) with English as their primary language (83.3%). All students that were in mainstream English or French classrooms (29% in French Immersion) were eligible for the study, providing that they did not have major sensory or motor impairment that would preclude the ability to complete the tasks or hear instructions. Stratifying for sex, this subsample of 204 was created by taking 2-3 students in each class from the highest, middle and lowest ranking levels of attention, based on teacher ratings of attentive behavior in the classroom, which were rank ordered. This smaller sample, representative of the continuum of attention across students, was then given more in-depth academic and cognitive assessments in the second half of each study year. As has been reported, the only significant difference between male and female participants was that females were more likely to have an informant (92.3% of informants were mothers) with less than high school education. Teacher reports indicated that 11.8% of sample had an Individual Education Plan (IEP) with 5.5% identified with ADHD, 3.8% a learning disability, 4.9% a language impairment, 1.6% a behavior difficulty, 0.5% a developmental disability.

Procedures

In accordance with procedures approved by the hospital and school board Institutional Review Boards, study information was presented in an initial meeting with principals of potential participant schools. Interested principals then contacted the research team, after which an information session for teachers was held at each participating school. Teachers and parents who gave written informed consent to participate in the current study completed questionnaire packages in November of Years 1 and 2 of the study. At the time of consent, parents were aware that their children might participate in either two or four testing sessions across the two years. Children who had written informed consent from parents and gave verbal assent, participated in academic testing sessions in November of Years 1 and 2 of the study. As described above, after the teacher-rated attentive behavior questionnaires were completed, a subset of students from each class, from the lowest, middle and highest bracket of the continuum of attention were selected to participate in further tests of cognitive and academic functioning. These further tests were administered to the same subset of 204 students in April of study Years 1 and 2. Hereafter, the November data collection wave is referred to as Year 1A or Year 2A and the April wave is referred to as Year 1B or Year 2B.

Measures

The following measures, including a behavior questionnaire, and standardized tests of academic achievement and WM were selected from a larger study that included a range of behavioral, cognitive and academic measures.

Assessment of classroom attention. Classroom attention was measured using the *Strengths and Weaknesses of Attention-Deficit/Hyperactivity Disorder Symptoms and Normal Behaviour Scale (SWAN),* completed by teachers in November of Year 1 and Year 2 of the study. This scale avoids the psychometric flaws of many negatively-worded 4 point behavioral measures, by scoring each item along a sensitive continuum of typical behavior, with positively worded probes (Swanson et al., 2001; Young, Levy, Martin, & Hay, 2009). The scale is divided into 'inattention' and 'hyperactivity' subscales. The inattention subscale only was employed in this study, considering the large body of evidence that links inattention with academic achievement, and does not provide evidence of such a link between hyperactivity and academic outcomes (Garner et al., 2014; Rabiner & Coie, 2000). Scores are distributed and coded based on a 7-point scale: 3 = Far below average, 2 = Below average, 1 = Slightly below average, 0 = Average, -1 = Slightly above average, -2 = Above average, -3 = Far above average. Negative scores indicate stronger attention; lower levels of inattentive behavior, while positive scores indicate weak attention; higher levels of inattentive behavior.

Measures of Math achievement. To assess students' math abilities across the two years, subtests from two commonly used batteries were administered at each wave of data collection.

The addition and subtraction probes from *AIMSweb® M-CBM, Mathematics Curriculum-Based Measurement* was used to test grade-level fluency in addition and subtraction. This reliable and valid measure assesses a range of math computation skills, taken from the school curriculum and standardized. Forms for grades 1-3 included 60 math fact problems (basic subtraction and addition), and forms for grade 4 students included 84 math fact problems. Math problems did not require borrowing or carrying, and contained digits 0-12, thus some computations were multi-digit. The content was the same for both forms, with the only difference being the number of available questions. The scoring is unique in that credit is given to each individual correct digit that appears in the solution. This allows for a more precise analysis of a child's math skills, as it captures emerging and partial skills as well as fully mastered skills. The test is administered in a group format, and students are given 2 minutes to complete as many problems as they can. This task is sensitive to both short-term and long-term improvement in student achievement, thus is appropriate for a longitudinal study design (Thurber, Shinn, & Smolkowski, 2002). Two subtests from the *Woodcock-Johnson - III Tests of Achievement (WJ-IIIACH)* were administered to further assess components of math achievement. Math Fluency and Math Calculation were used from the "Math ability" cluster. The WJ-IIIACH is a highly reliable standardized battery that can be used throughout the academic trajectory (Woodcock, McGrew, & Mather, 2001a). Math fluency is a timed test in which students complete as many basic math facts as possible within a 3 minute time limit. Seven minutes is given for the calculation task, although time is not emphasized in the instructions, and the difficulty of the questions increase as the student progresses. Students are asked to complete as many questions as they can, and to skip problems they do not know.

Measures of reading achievement. Reading fluency was assessed using the *Dynamic Indicators of Basic Early Literacy Skills (DIBELS, 5th ed), Oral Reading Fluency Subtest* (http://dibels.uoregon.edu/measures/materials.php). This test is an individually administered curriculum-based measure (CBM) of oral reading fluency. Students are given 3 grade level passages to read out loud, and are instructed to read as accurately as possible, and to read as many words as they can within one minute. Points are deducted for omissions, substitutions, inaccurate pronunciation and hesitations over 3 seconds. The median number of errors across the three passages is scored, as is the median number of correct words; this latter score was used as the oral reading fluency measure in the current study. One subtest from the *Woodcock-Johnson - III Tests of Achievement*, Letter-Word Identification, was used from the "Reading ability" cluster of this battery in order to test fluent word reading ability. This subtest presents single words listed on a page and words increase in difficulty as the student progresses. Credit is given if the word is said out loud smoothly and accurately.

Assessment of working memory. In order to assess WM the following two tests were chosen for their strong psychometric properties and in order to extend previous findings using these measures. The *Wechsler Intelligence Scale for Children (WISC-IV), Digit Span Subtests (DS)* is a widely-used test of auditory-verbal WM (Wechsler, 2003). The test requires participants to listen to and recall a series of digits. In the Digit Span Forward task, participants are asked to recall the digits exactly as heard, while in the Digit Span Backward task, participants are asked reproduce the digits heard in backward sequence. The standardized composite score of these two tasks was used in the current study. The *Wide Range Assessment of Memory and Learning (WRAML-2), Finger Windows Forward Subtest (FWF)* was administered in order to assess visual-spatial WM. This test of WM taps into the visual-spatial storage component of WM

(Sheslow & Adams, 2003). Participants are presented with an 8x11 plastic grid with 'windows' distributed throughout the grid. Participants, who are seated directly across from the examiner, are asked to replicate the examiner's visual sequence, created with a pencil tapping different sequences of 'windows.' The sequence becomes longer as participants progress. A standardized score is calculated from the total number of correct sequences that the participant is able to replicate.

Statistical Approach

Missing data was imputed according to the methods suggested by McKnight, McKnight, Sidani, & Figueredo (2007), when not more than 10-15% of data is missing. No significant outliers were detected. Assumptions of normality and homoscedasticity were satisfied, with the exception of the Year 2B Math Addition variable, where the Levene's test was significant for the male sample (however, the test was not significant for the full sample). As a precaution, the HC3 test in the SPSS macro PROCESS (Preacher & Hayes, 2008) was used to produce heteroscedasticity-consistent standard error estimates for this variable.

Relationships between study variables. Partial correlations were calculated to examine the relationship between all study variables. Age was placed as a control variable, as it is an important factor in CBMs across grades and initial analysis indicated that age was differentially related to WM variables.

Mediation analysis. All mediation models were designed with visual-spatial WM and auditory-verbal WM at Year 1B as parallel mediators between inattention at Year 1A and academic outcomes at Year 2B. Mediation analyses were carried out using the PROCESS macro for SPSS, developed by Preacher & Hayes (2008). The procedures suggested by Hayes (2013) allow for detecting the difference between the direct effect of a predictor on an outcome variable, and the indirect effect after accounting for the mediator. Using this macro also allows for testing the relative strength of auditory-verbal WM and visual-spatial WM as mediators within each analysis (Hayes, 2013). Covariates, including sex, age, parental education and Y1A academic scores were added in each analysis. This model allows for partialling out the influence of baseline academic scores collected at Year 1A and examining influences of each variable across time. Outcome variables were examined in separate models instead of in one simultaneous model in order to elucidate the role of inattention and WM in the development of specific skills within math and reading at the elementary school level. All analyses were carried out with IBM SPSS version 21.

Results

Correlations between study variables

Partial correlations between all study variables, controlling for age, are presented in Table 1. Teacher-rated inattention, measured at Year 1A, was significantly correlated in the expected direction with WM measures at Year 1B and all academic outcome variables at Year 2B. All main study variables were significantly correlated in the expected direction at the .01 level, with the exception of visual-spatial WM and auditory-verbal WM which were not significantly correlated. In terms of study covariates, sex was significantly correlated with attention at the .01 level, and with reading fluency, math subtraction and visual-spatial WM at the .05 level. Parent education was weakly to moderately correlated with all variables, with the exception of visual-spatial WM, which appears to be related to sex but not to parental education in this sample. Conversely, auditory-verbal WM was not related to sex, but was weakly correlated with parental education.

[INSERT Table 1. Partial Correlations, Controlling for Age, Between Study Variables for Full Sample (N = 204)]

Mediation analyses

Mediation analysis with two parallel mediators, conducted using ordinary least squares (OLS) path analysis, revealed that behavioral inattention indirectly influenced math addition and subtraction outcomes through its effect on visual-spatial WM (see Figures 1 and 2). Children who displayed higher levels of behavioral attention at the beginning of Year 1 (negative scores correspond to better attention) had higher visual-spatial WM scores (a = -0.06) at the end of Year 1, and children with higher WM scores had stronger scores on math outcomes at the end of Year 2 (addition b = 0.62, subtraction b = 0.57, $p < 0.05$). A bias-corrected bootstrap confidence interval for the indirect effect (addition ab = -0.04, subtraction ab = -0.05), based on 10,000 bootstrap samples was entirely below zero (addition -0.10, -0.00; subtraction -0.10, -0.02). There was also evidence that behavioral inattention influenced math scores the following year independently of its effect on WM (addition c' = -0.33, $p < .001$, subtraction c' = -0.21, $p < .001$).

[INSERT Figure 1. Visual-spatial WM as a mediator of the relationship between teacher-rated inattention and math addition scores one year later.]

[INSERT Figure 2. Visual-spatial WM as a mediator of the relationship between teacher-rated inattention and math subtraction scores one year later.]

This model was also significant for math calculation scores as the outcome variable, see Figure 3. However, when predicting academic fluency measures (math, reading), WM did not mediate the significant direct relationship between behavioral inattention and fluency scores measured one year later. All analyses included sex, age, parental education and academic scores at Year 1 as covariates. Significant predictors of math fluency at Year 2B included inattention at

Year 1A ($b = -0.17$, $p < .01$), sex ($b = -3.31$, $p < .05$), age ($b = -2.48$, $p < .01$), and math fluency scores at Year 1A ($b = 0.68$, $p < .001$). For reading fluency at Year 2B, predictors were auditory-verbal WM at Year 1B ($b = 1.68$, $p < .05$), parental education ($b = 3.12$, $p < .01$), and Year 1A reading fluency scores ($b = 0.76$, $p < .001$).

[INSERT Figure 3. Visual-spatial WM as a mediator of the relationship between teacher-rated inattention and math calculation scores one year later.]

To investigate this same model using WM scores at Year 2B, which allows us to control for previous levels of WM at Year 1B (which we cannot do when using Year 1B scores as the mediating variable), we modeled inattention at Year 1A as the independent variable, academic outcomes at Year 2B as outcome variables with WM at Year 2B as a potential mediator. Results replicate the first model in that visual-spatial WM was a significant mediator of the relationship between inattention and math calculation, the confidence interval for the indirect effect was entirely below zero (-0.08, -0.01). However WM was not a significant mediator for math fluency, CBM addition and subtraction and reading outcomes. Results from this model need be interpreted with caution, as WM at Year 2B was collected at the same time point as the outcome variables, thus are subject to issues with reverse causation.

A reverse model was conducted in order to confirm directionality of the predictor and mediating variables. No mediation models were significant when reversing the role of mediator and independent variable, with Year 1B WM modeled as the independent variable, Year 2A teacher-rated inattention as the mediating variable, Year 2B academic variables as outcomes, and sex, age, parental education, Year 1A academic scores, and Year 1A attention scores as covariates.

Discussion

The present study contributes to our understanding of the longitudinal relationships between classroom inattention, WM and math and reading outcomes in a community sample of elementary school children. We hypothesized that inattention would directly and indirectly influence math outcomes through auditory-verbal and visual-spatial WM, and influence reading outcomes through auditory-verbal WM. Using OLS regression based mediation analyses, we found support for a model in which children's classroom inattention, as rated by teachers at the beginning of the school year, was indirectly associated with math outcomes one year later through visual-spatial WM. There was also a significant direct association between teacher rated inattention and all measured math outcomes the following year. These findings were partially consistent with our first hypothesis; the proposed model held for math CBM addition and subtraction scores as well as calculation outcomes, but not for math fluency as measured by the WJ-IIIACH. Based on previous findings that implicate auditory-verbal WM in math outcomes (Rogers et al., 2011), we expected this domain of WM to be a mediator, however this hypothesis was not confirmed in the current study.

These new findings raise interesting questions about the role of auditory-verbal WM across academic outcomes, as well as about the specific influences of visual-spatial WM on different aspects of math skill development.

Firstly, the CBM addition and subtraction tests and the WJ-IIIACH math fluency test all measure some aspect of fluency; they are timed tests in which participants are asked to quickly and accurately solve simple math problems. However, there are differences between these two measures that may account for the differential influence of WM ability. For example, the CBM tests include double-digit addition and subtraction (i.e. 10+12), whereas the WJ-IIIACH questions include only single digit arithmetic (i.e. 3+4, 10+1). Although no carrying or borrowing is required in the CBM test, some algorithmic knowledge of procedures and sequences for double-digit calculation is needed. The WJ-IIIACH fluency also has fewer items at each level of difficulty. Another difference between the two measures is that CBM scoring is more sensitive to developing skill, as any correct number that appears in the answer merits one point. Therefore, it follows to reason that the influences of inattention on higher-level math outcomes, which require more attention to algorithm and less reliance on fluent retrieval, are partially accounted for by WM ability, in the visual-spatial domain that is consistently linked to math outcomes (Alloway & Passolunghi, 2011; Li & Geary, 2013; Rogers et al., 2011). Furthermore, our results that differentiate math fluency from higher-level calculation can be considered in the context of genetic studies which provide evidence that math fluency is a distinct construct from other domains of math (Petrill et al., 2012).

Although math fluency shares significant variance with inattention and both domains of WM (Gray, Rogers, Martinussen, & Tannock, submitted manuscript), the current study provides evidence that children's classroom inattention (as rated by teachers) directly influences their math fact fluency across time, and indicates that WM is not a mediator nor predictor, when controlling for sex, age and math fluency scores at Year 1 (all significant predictors of math fluency at Year 2).

The finding that auditory-verbal WM did not significantly predict math outcomes in arithmetic fluency or algorithmic computation is consistent with the results of Fuchs et al. (2006). They also found that attentive behavior was predictive of arithmetic and algorithmic computation. However, other studies have found that auditory-verbal WM does play a role math outcomes (Fuchs et al., 2005; Hecht, Torgesen, Wagner, & Rashotte, 2001). Differences may be due to the use of a math composite score, including higher level math skills that are more strongly associated with verbal WM and executive skills (Swanson, 2011). In addition, although our sample size did not allow for separate mediation analyses within each grade, differences in relative contribution of auditory-verbal WM to math skills between grades were found in the cited studies. Therefore, another possibility is that the children in our sample are young (mean age is 7.67) and may rely mostly on visual-spatial WM to process information at this stage, not having gone through the developmental shift toward relying more on auditory-verbal WM for information processing (Fastenau, Conant, & Lauer, 1998).

Another main hypothesis in the current study was that inattention would indirectly influence word reading and reading fluency outcomes, through auditory-verbal WM. We did not find such an indirect effect, and interestingly, the direct effect of inattention at Year 1 on Year 2 reading fluency and word reading scores was also not significant. In the context of other studies in which inattention is a predictor of reading fluency (for example, Pham, 2013), it is important to note that in the current study, inattention and WM were modeled along with covariates, including parental education, age and Year 1 reading fluency scores, which all significantly predicted reading fluency scores at Year 2. Contrary to expectations, inattention did not appear to play a significant role in predicting reading scores one year later, however, auditory-verbal WM was significant predictor. Thus, although not found to play the hypothesized mediating role, auditory-verbal WM is positioned as an important factor in the development of reading fluency across the elementary school years. These results are consistent with the findings of Li and Geary (2013), who also found that visual-spatial WM was not a predictor of reading outcomes, but that gains in visual-spatial WM were associated with stronger math scores at the end of elementary school.

Although outside the scope of this paper, future studies could seek to account for other mediators within the relationship between inattention and academic fluency. For example, teacher instructional supports, parent factors, and individual factors are all important to consider as mediating variables (Daley & Birchwood, 2010).

Strengths of this study include the large sample size, as well as the longitudinal design, in which the predictor is collected before the mediating variables, and the outcome variables are collected one year later. Separation of WM domains and academic skill outcome variables allowed for a more specific understanding of these relationships across two school years. Practical considerations limited data collection time points, such that our mediating variable was collected at 2 time points across two years, whereas the outcome variables were collected at 4 time points. It would have been ideal to have baseline WM measures, however, time allotted by the school for each testing session as well as date restrictions did not permit for collecting cognitive measures for the full sample of 524. Strengthening the confidence in outcomes is the fact that when reverse modeling WM and inattention, where WM is placed at the predictor, and inattention as the mediator, WM measures at Year 1 do not predict levels of inattention in Year 2. Our outcomes regarding visual-spatial WM are afforded more confidence, as we were able to run the analysis with WM at Year 2 as the mediating variable, thus accounting for the influence of prior WM scores (at Year 1). This model continued to reach significance for calculation outcomes, however this model is interpreted with caution, as WM measures at Year 2 were collected at the same time point as the academic outcome measures. Therefore, although further evidence is needed to substantiate the developmental directionality between inattention and WM, these findings add to our knowledge about longitudinal predictors of academic outcomes in elementary school children and further specify the nature of the relationship between inattention, WM and academic outcomes across elementary school, for typically developing children.

Conclusions

Findings confirm and replicate the body of literature that positions attention as a robust predictor of later math achievement, including fluency and algorithmic computation, in typically developing elementary school children. Contrary to findings from cross-sectional studies, our findings provide evidence that auditory-verbal WM is a more robust predictor of reading fluency across two school years, as compared to teacher-rated attention, which did not predict reading outcomes. Main findings emphasize that visual-spatial WM partially accounts for the relationship between teacher-rated attention and math arithmetic and calculation skills across the elementary school grades.

Table 1

Partial Correlations, Controlling for Age, Between Study Variables for Full Sample (N = 204)

Variables	1	2	3	4	5	6	7	8	9	10
1. Teacher-rated Inattention	–									
2. Letter-word Identification	-.49**	–								
3. Reading Fluency	-.54**	.81**	–							
4. Math Fluency	-.42**	.48**	.58**	–						
5. Math Calculation	-.48**	.49**	.51**	.66**	–					
6. Math Addition	-.48**	.42**	.52**	.84**	.59**	–				
7. Math Subtraction	-.40**	.44**	.47**	.83**	.58**	.82**	–			
8. Auditory-Verbal WM	-.23**	.31**	.35**	.33**	.33**	.30**	.34**	–		
9. Visual-Spatial WM	-.34**	.24**	.24**	.29**	.33**	.33**	.32**	.14	–	
10. Sex	-.37**	.08	.16*	-.08	.08	-.00	-.15*	-.05	.16*	–
11. Parent education level	-.22**	.23**	.31**	.19**	.22**	.20**	.24**	.16*	.10	.03

Significant correlation: * $p < .05$. ** $p < .01$.

Measured at Year 1 Time A: Teacher-rated Inattention, Age, Sex, Parent education level.

Measured at Year 1 Time B: All working memory measures.

Measured at Year 2 Time B: All academic measures.

Teacher-rated Inattention, Math Addition and Subtraction, total raw score. Reading and Math Fluency, Math Calculation and Letter-Word Identification, WM variables: Standard Scores.

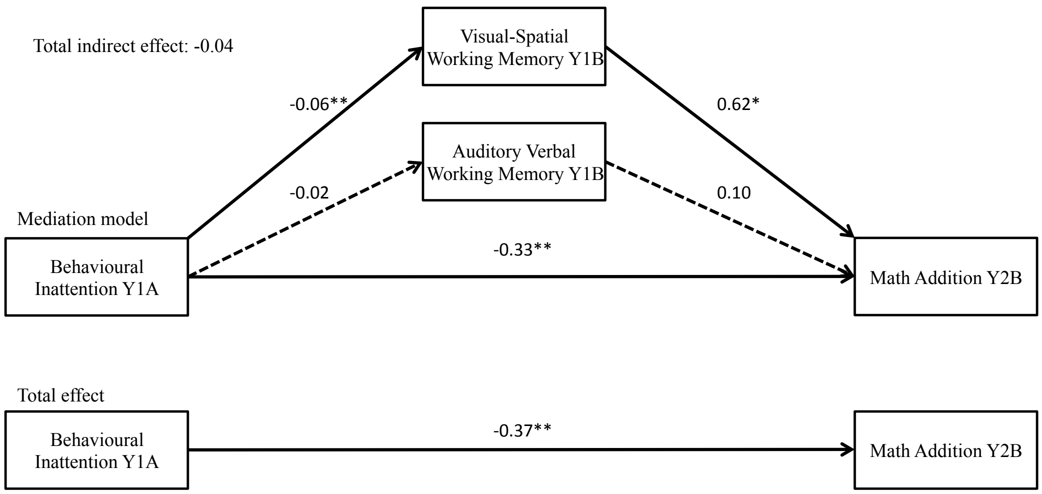

Figure 1 Visual-spatial WM as a mediator of the relationship between teacher-rated inattention and math addition scores one year later. Unstandardized regression coefficients are presented. * $p < .05$, ** $p < .01$

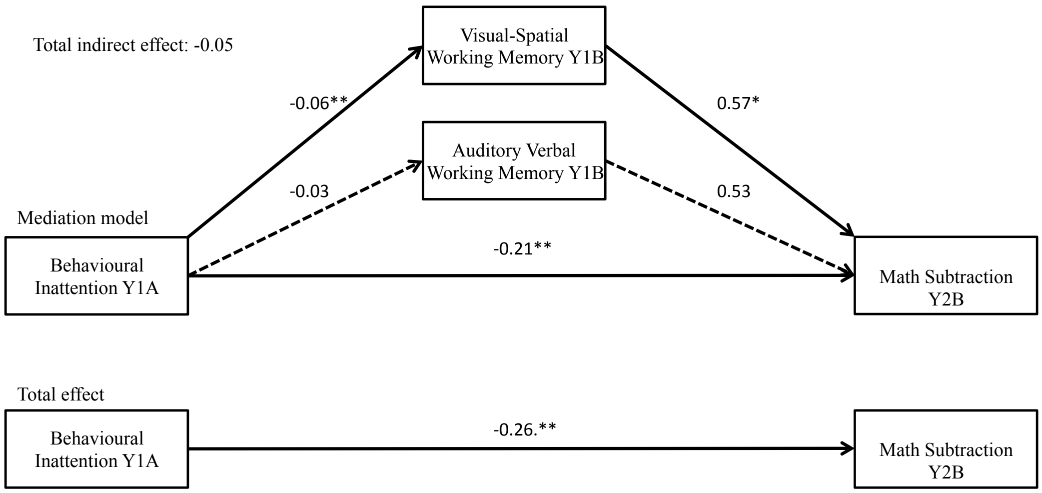

Figure 2 Visual-spatial WM as a mediator of the relationship between teacher-rated inattention and math subtraction scores one year later. Unstandardized regression coefficients are presented. * $p < .05$, ** $p < .01$

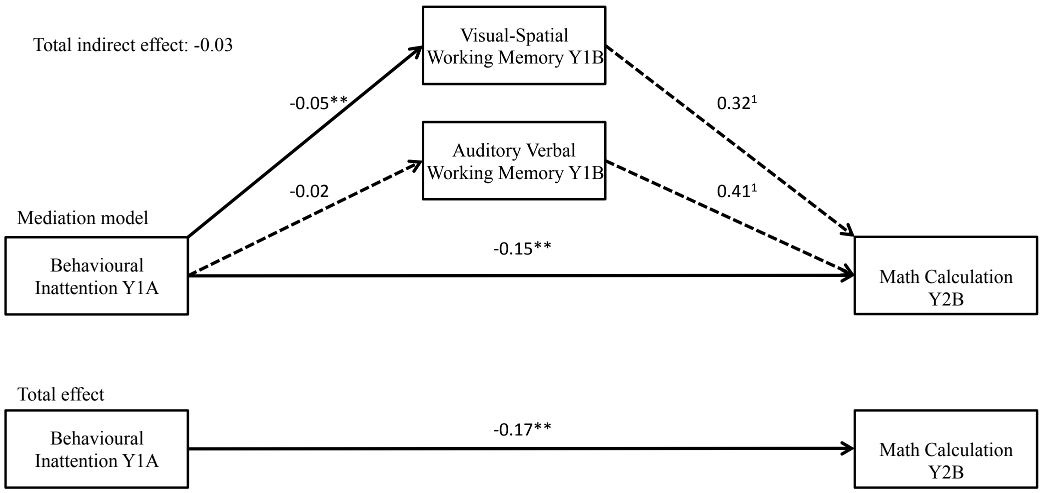

Figure 3 Visual-spatial WM as a mediator of the relationship between teacher-rated inattention and math calculation scores one year later. Unstandardized regression coefficients are presented.
[1] $p = 0.05$,* $p < .05$, ** $p < .01$.

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