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Domain General Mediators of the Relation between Kindergarten Number Sense and First-Grade Mathematics Achievement

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Abstract

Domain general skills that mediate the relation between kindergarten number sense and first-grade mathematics skills were investigated. Participants were 107 children who displayed low number sense in the fall of kindergarten. Controlling for background variables, multiple regression analyses showed that attention problems and executive functioning both were unique predictors of mathematics outcomes. Attention problems were more important for predicting first-grade calculation performance while executive functioning was more important for predicting first-grade performance on applied problems. Moreover, both executive functioning and attention problems were unique partial mediators of the relationship between kindergarten and first-grade mathematics skills. The results provide empirical support for developing interventions that target executive functioning and attention problems in addition to instruction in number skills for kindergartners with initial low number sense.

Keywords

mathematics achievement; mediation; executive functioning; attention; low number sense

Introduction

Proficiency in early number sense is vital to building a foundation for children's later academic success. The preschool and kindergarten number sense "core" encompasses skills related to number, number relations, and number operations and is highly relevant to learning mathematics in elementary school (Jordan et al., 2006; Malofeeva et al., 2004; National Research Council, 2009). Longitudinal research demonstrates that kindergarten and first-grade mathematics skills matter for achievement in later elementary school and beyond (Duncan et al., 2007; Jordan, Glutting, & Ramineni, 2010a; Jordan, Kaplan, Ramineni, & Locuniak, 2009). In the absence of evidenced-based interventions, early weaknesses in number sense often cascade into more severe difficulties (Fuchs, Fuchs, & Compton, 2012; Hart & Risley, 1995; Jordan et al., 2009).

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Low-income children typically enter kindergarten with weaknesses in number sense, relative to their middle-income peers (e.g., Jordan, Kaplan, Oláh, & Locuniak, 2006). However, children from all socioeconomic backgrounds may begin kindergarten with low number sense; young children do not develop number skills at the same pace, and substantial individual differences can be seen in early childhood (Clements & Sarama, 2009). Some children who enter kindergarten with low number sense catch up to their normally achieving peers through kindergarten instruction, although many others show relatively flat growth trajectories (Jordan et al., 2006). The goal of the present study was to identify potentially malleable domain general factors that mediate the established relation between children's kindergarten number sense and mathematical achievement in first grade, namely executive functioning and attention problems, for children demonstrating early mathematics difficulties. Such skills might support number learning and help high-risk children take advantage of early interventions in mathematics (Clark, Sheffield, Wiebe, & Espy, 2013).

Early Number Sense

It is well known that early facility with numbers plays a key role in learning conventional mathematics. By kindergarten entry, most children can verbally subitize small quantities (i.e., name the cardinal number for small sets of objects immediately, without counting) and enumerate sets to at least five. Understanding of one-to-one correspondence and the cardinality principle (Gelman & Gallistel, 1978) helps children see relationships between and among numbers. Knowing that the next number on a number line is exactly one more than the previous one ($n + 1$) facilitates addition skills (Baroody, Eiland, & Thompson, 2009); children can solve simple arithmetic problems by counting on from a cardinal value. Children's abilities to do simple arithmetic calculations at the beginning of kindergarten are strongly predictive of their later success in mathematics (Jordan et al., 2009). As children build their knowledge of small numbers, they more easily learn to count, compare, and manipulate larger numbers (Jordan, Fuchs, & Dyson, in press).

Intervention studies demonstrate the importance of number sense to mathematical learning (Chard et al., 2008). Jordan and colleagues (Dyson, Jordan, & Glutting, 2013; Jordan et al., 2012) tested a small group number sense intervention for kindergartners who were not progressing in mathematics by mid-year. The intervention targeted number, number relations, and number operations, all competencies that underlie mathematics difficulties. In a randomized study, it was found that children in the number sense intervention made lasting improvements in mathematics relative to control children (i.e., small group language instruction and business-as-usual) with moderate to large effect sizes. The intervention children performed better than controls on an immediate posttest as well as several months later.

Executive Functioning

Although number sense is a gateway to learning mathematics, weaknesses in domain general skills related to executive functioning may further constrain children's numerical development (Steele et al., 2012). Executive functioning includes processes related to working memory, inhibition and set shifting, and updating for goal directed activities (Blair, Zelazo, & Greenberg, 2005; Carlson, 2005; Zelazo, Müller, Frye, & Marcovitch, 2003; Kolkman, Hoijtink, Kroesbergen, & Leseman, 2013). Importantly, executive functioning may be malleable. Research has shown that curricula, such as Tools of the Mind, have generated improvements in executive functioning (Barnett et al., 2008). Children's executive functioning skills are closely associated with mathematics performance (Bull & Scerif, 2001; Clark, Pritchard, & Woodward, 2010; Clark et al., 2013; Espy et al., 2004). Among other researchers, Blair and Razza (2007) found asymmetrical divergent associations

between executive functioning and children's reading and mathematics achievement, with much stronger relations observed between executive functioning and early mathematics.

Executive functioning seems to help children on specific numerical tasks. For example, Kolkman et al. (2013) found that verbal updating skills (i.e., the ability to monitor, code, and revise on a listening recall task) are related to improvements on numerical estimation tasks in 5-year-old children. Additionally, when children count up from a quantity to solve an addition problem, working memory helps them keep track of the first number and the number that is being counted (Geary, Hoard, & Hamson, 1999). To solve a story problem, such as, "Jane has 2 cookies and Jim gives her 1 more cookie. How many cookies does Jane have now?" learners must identify the addends and the appropriate operation, and then, while maintaining this information in their working memory, calculate the correct response. Deficits in working memory may prolong the development of effective counting strategies and thus delay mastery of basic skills, especially in children who might have weak number sense from the start (Siegler, 2007). Inhibition and set shifting are important when solving combinations, such as $2 + 3$. For instance, a counting string intrusion may induce children to answer "4", the next number in the sequence, because they cannot inhibit this counting response when solving the combination (Geary, 2010). Moreover, when solving sets of calculations, children may have trouble switching between operations; adding when they are supposed to subtract is a common error for young children (Jordan & Montani, 1997).

Classroom Attention

In the classroom, children must maintain attention while ignoring distractions (Passolunghi, Cornoldi, & De Liberto, 1999; Swanson et al., 2004). Sometimes included under the umbrella of attention are hyperactive/impulsive classroom behaviors, which manifest through the inability to regulate extreme levels of activity as well as the inability to use forethought to plan out appropriate actions and behaviors (DuPaul et al., 1997). Factor analyses, however, suggest the need to measure classroom attention problems and hyperactive/impulsive behaviors separately, due to potentially different effects on academic and social outcomes (DuPaul, 1991; Rabiner et al., 2000). Primarily, studies measuring classroom attention with teacher rating scales have shown that attention problems, as opposed to hyperactive/impulsive behaviors, are most predictive of mathematics outcomes (Dally, 2006; Lonigan et al., 1999).

Although Steele et al. (2012) found that teacher ratings of attention problems and hyperactivity/impulsivity did not predict numeracy outcomes -- either concurrently or longitudinally -- in typical kindergartners, many other studies have found that children with early mathematics difficulties often have co-occurring attention problems (Rabiner et al., 2000). Duncan and colleagues (2007) determined that attention at school-entry, as measured by teacher and parent ratings, strongly predicted children's mathematics achievement through middle school. By separating attention problems from aggression and other maladaptive behaviors, attention has been found to be the most predictive behavior of later academic achievement (Barriga et al., 2002; Konold & Pianta, 2005; Trzesniewski, Moffitt, Caspi, Taylor, & Maughan, 2006). However, attention problems are not unchangeable; children can grow and mature into more focused learners over time.

Teacher ratings of attention differentiate children with mathematics learning difficulties from their typically achieving peers. Fuchs et al. (2005) examined cognitive determinants of mathematics disabilities for first-grade students; they found that teacher ratings of attention problems most robustly predicted children's end of first grade scores on all mathematics measures that were administered—including assessments of story problems, fact retrieval, concepts/applications, and computation. For children in first through third grades, Swanson (2006) found that children's ability to focus their attention on relevant tasks predicted their

computational mathematics achievement. Cirino, Fletcher, Ewing-Cobbs, Barnes, and Fuchs (2007) and Raghobar and colleagues (2009) showed a similar relationship between mathematics difficulties and classroom attention for older elementary students.

Present Study

Number sense, executive functioning, and aspects of classroom attention have all been shown to be predictors of achievement in mathematics. However, the relations and interactions among these precursors are not clear, particularly for children with low number sense in kindergarten, who are at risk for later mathematics difficulties (e.g., Jordan et al., 2009).

The present study extends previous findings by examining the relation of both executive functioning and classroom attention to first-grade mathematics outcomes while controlling for kindergarten number sense, nonverbal ability, and other background variables (i.e., age, gender, and English language learner status). We looked at the extent to which kindergarten number sense is directly related to first-grade mathematics and the extent to which executive functioning and classroom attention mediate these relationships for children with low initial number sense. Clarifying these relations is potentially important for developing interventions that focus not only on developing number competencies but also cognitive (executive functioning) and behavioral (attention) factors. We used a broad measure of executive functioning, including inhibition, set shifting, and working memory, components which have all been shown to affect mathematics performance (Bull & Scerif, 2001; Clark, Pritchard, & Woodward, 2010; Clark et al., 2013; Espy et al., 2004). In particular, we used a conflict activity that requires children to initiate goal-directed behavior in the face of competing stimuli (Carlson, 2011). Children's classroom attention problems and hyperactive behavior were assessed through teacher report. For contrast, we examined predictors of first-grade reading achievement in addition to mathematics outcomes.

Method

Participants

Children were recruited from kindergarten classes in four schools in the same school district in the mid-Atlantic region of the U.S. Three of the schools served primarily high-risk children from predominately low-income, minority families and one school served children from a range of SES levels. The percentage of children enrolled in the free/reduced lunch program ranged from 60.1% to 95.6% in each school, with the mean being 82.4%. Informed consent letters were sent home with every kindergartner. All consenting children ($n = 214$) were screened on their number knowledge with the *Number Sense Brief* (NSB; Jordan, Glutting, Ramineni, & Watkins, 2010b). Children ($n = 132$) who received the lowest scores (< 22) were assessed on all of the study measures. Based on normative data for the NSB, a raw score of 22 is approximately the 32nd percentile of students in the fall of kindergarten (Jordan & Glutting, 2012). Scoring below the 35th percentile has typically been used to identify students at risk for mathematics difficulties (Mazzocco, 2007). Twenty-five of the low-achieving children did not complete all assessments, leaving a final sample size of 107 children. The results of Little's (1988) Missing Completely at Random (MCAR) test were not significant, indicating that the data were missing wholly at random. Table 1 presents participant demographics.

A priori power was assessed for both the multiple regression analysis (MRA) and mediation analyses. By setting $\alpha = .05$ with nine predictors, with power equal to the standard .80, given a medium effect size of $f^2 = .15$ (according to Cohen's (1988) criteria of $f^2 = .02$ as small, $f^2 = .15$ as medium, and $f^2 = .35$ as large) the obtained sample size of 107 used for the MRAs

satisfied requirements. Power for the mediation analyses used the procedure recommended by Fritz and MacKinnon (2007). Specifically, assuming medium effect sizes for the “a” and “b” paths in the mediation model (discussed below), the mediation analyses required a minimum sample size of 87.

Measures

Number sense—The NSB (Jordan et al., 2010b) assesses children’s skills related to counting (e.g., “I’d like you to count as high as you can, but I bet you are really good at counting, so I’ll stop you when you’ve counted high enough.”), number recognition (e.g., “I am going to show you some numbers, and I would like for you to tell me their names: 4, 9, 13, 28, 37, 82, 124.”), numerical magnitude comparisons (e.g., “What number comes right after 7?”), nonverbal calculations (e.g., The child is shown 3 dots which are then covered by a box lid. Two more dots are then slid under the box. The child is shown 4 pictures of dots, each in a horizontal line, with different totals and is instructed, “Point to the picture that shows how many dots are hiding under the box now.”), arithmetic story problems (e.g., “Jill has 2 pennies. Jim gives her 1 more penny. How many pennies does Jill have now?”), and arithmetic number combinations (e.g., “How much is 2 plus 1?”). The items on the NSB are scored incorrect (0) or correct (1) with a total raw score of 44. The NSB is internally consistent, with a coefficient alpha greater than .80 in the fall, winter, and spring of kindergarten and the fall and winter of first grade (Jordan et al., 2009).

Executive functioning—The *Conflict EF Scale* (CEFS; Carlson, 2011) is a valid and reliable measure of “cool” executive functioning ability in young children (Beck, Schaefer, Pang, & Carlson, 2011). The CEFS assesses students’ overall executive functioning skills by tapping a variety of areas including: inhibition, set shifting, and working memory (Carlson, 2011). Conflict tasks have been shown to relate to students’ theory of mind and academic learning (Carlson & Moses, 2001). They require children to initiate a goal-directed behavior in the face of competing or conflicting stimuli, which is very relevant to the expectations of students in the classroom setting. The CEFS uses a complex sorting activity to assess children’s EF abilities and generates a single, total raw score out of a possible 70. Children are asked to sort stimulus cards according to a rule. In the beginning, children must sort the stimulus cards by color and then by shape. Next, children are asked to switch between these rules within the same deck. Finally, at the most difficult level, children are asked to sort by color or by shape based on the presence or absence of a dark black line around the border of the stimulus card. The assessment takes between 5–7 minutes to complete for kindergartners. The CEFS has a high test-retest reliability with an intraclass correlation coefficient of .93 and shows no evidence of practice effects (Beck et al., 2011).

Teacher-rated inattention and hyperactivity—The *Strength and Weaknesses of ADHD—Symptoms and Normal-Behavior Scale* (SWAN; Swanson et al., 2004): *Attention Problems* and *Hyperactivity/Impulsivity* subscales were used to measure children’s levels of attentiveness and hyperactivity/impulsivity. The scale includes the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.) (DSM-IV; American Psychiatric Association, 1994) attention-deficit/hyperactivity disorder criteria for attention problems (e.g., sustain attention on tasks or play activities) and hyperactivity/impulsivity (e.g., sit still, control movement of hands/feet or control squirming). Nine items are included for each subscale. Teachers were asked to rate students on individual items using a scale of –3 to 3. Raw scores are a mean score calculated by adding the scores for each item in the subscale and dividing by 9. The SWAN is correlated with other assessments of attention problems and hyperactivity/impulsivity (Swanson et al., 2004). Internal consistency is high for the SWAN subscales ($\alpha = .92$ for Attention Problems; $\alpha = .94$ for Hyperactivity/Impulsivity) (Lakes, Swanson, & Riggs, 2012).

Mathematics achievement—Mathematics achievement was assessed with the *Woodcock-Johnson III Tests of Achievement* (WJ; Woodcock, McGrew, & Mather, 2007): Applied Problems and Calculation subtests. Average internal reliability is high for both for Applied Problems ($r = .90$) and Calculation ($r = .97$) subtests (Woodcock et al., 2007). On the Applied Problems subtest, the tester read problems aloud to children. Items required the use of quantitative reasoning (starting with simple counting questions, then orally presented story problems with pictures, and finally orally presented story problems without pictures). The Calculation subtest gauged computation in a written format with standard symbols.

Reading achievement—Children's reading skills were assessed with the *Woodcock-Johnson III Tests of Achievement* (Woodcock et al., 2007): Letter/Word Identification subtest. For the age range of the children in the study, internal reliability on both versions is high ($r > .90$) (Woodcock et al., 2007). In the Letter/Word Identification subtest, the examiner asked children to identify one letter from a group of four letters, numbers, or pictures. Then, children were asked to read whole words of increasing difficulty.

Nonverbal reasoning—The *Wechsler Preschool and Primary Scale of Intelligence* (WPPSI; Wechsler, 2002) Matrix Reasoning subtest was used to assess children's nonverbal ability. Internal reliability is strong ($r = .90$). For the age range of the children in the study, the Matrix Reasoning subtest is correlated with the WPPSI overall performance IQ score ($r = .63$). Children were asked to look at a matrix with a missing image and then select the correct picture from a bank of four or five choices.

Procedure

Children were tested individually in school. All measures were given by one of six trained graduate students in education. In November of kindergarten, children were given the NSB; in March of kindergarten, they were assessed on executive functioning and classroom attention. In October of first grade, children were reassessed on the NSB as well as on the WJ mathematics and reading tests and the WPPSI nonverbal reasoning test.

Data Analyses

Data were first analyzed using three direct-entry (standard) multiple regression analyses (MRA). The MRAs were conducted to assess longitudinal relationships between predictors (nonverbal reasoning, kindergarten number sense, kindergarten executive functioning, kindergarten classroom attention) and the dependent variables (first grade number sense, applied problems, calculation, and reading achievement). Four separate MRAs were conducted to predict first grade number sense, applied problems, calculation, and reading achievement, respectively. Demographic variables (kindergarten start age, ELL status, and gender) were included in the reported MRAs, but only kindergarten start age was significant for WJ Calculation and Reading (i.e., older children performed better on these two assessments). All other demographic variables were not significant.

Mediation analyses were completed using Preacher and Hayes' (2008) SPSS macro for simultaneously testing multiple mediators. Unlike the more well known mediation methods of Baron and Kenny (1986) and Sobel (1982), the Preacher and Hayes (2008) procedure allows researchers to test multiple mediators within a single analysis. As a result, it is possible to evaluate the relative strength of mediators against one another. Likewise, the Preacher and Hayes (2008) analyses are bootstrapped, which makes them more accurate with small sample sizes (MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002; Preacher & Hayes, 2008). Bootstrapping is also robust to violations of the normality assumption required by the Baron and Kenny and Sobel procedures (Efron & Tibshirani, 1993; Manly,

1997; Preacher & Hayes, 2008.) Finally, the Preacher and Hayes method allows for the inclusion of covariates to control for other variables in the model.

Mediation analyses uncover the difference between the direct effect of a predictor on an outcome (c path), and the indirect effect of a predictor on an outcome after accounting for the mediator(s) (c' path) (Preacher & Hayes, 2008). The size of the indirect effect is determined by both the impact of the predictor on the presumed mediator (a path) and the relationship between the mediator and the outcome (b path) (Preacher & Hayes, 2008). The amount of mediation is defined as $c - c'$ and/or $a*b$ (cf. Baron & Kenny, 1986 for mathematical derivations). For our analyses, $a*b$ was used to denote the amount of mediation.

Upon inspection of the MRAs, mediation models were tested using executive functioning and classroom attention as mediators between kindergarten number sense and first grade number sense, applied problems and calculation, respectively. For contrast, kindergarten number sense and classroom attention were examined as mediators between kindergarten reading achievement and first grade reading achievement.

Results

Mean raw (or percentile) scores and standard deviations are presented in Table 2 for all measures by time. As seen by the standard deviations, there was sufficiently variability on the measures in the study, even though participants were selected on the basis of low number sense performance. Pearson correlations between measures are presented in Table 3. All correlations were positive and most statistically significant.

The results of the MRAs with the four dependent variables (first grade number sense, calculation, applied problems, and reading) are presented in Table 4. The MRA predicting first grade NSB number sense scores was significant, $R^2 = .616$, $F(9, 97) = 17.31$, $p = .001$. Four predictors made unique contributions to children's first grade number sense: attention problems, kindergarten number sense, nonverbal reasoning, and executive functioning. The relative contribution of each independent variable was evaluated through the comparison of standardized beta coefficients (Cohen, Cohen, West, & Aiken, 2003; Keith, 2006; Pedhazur, 1997). Kindergarten number sense made the largest unique contribution to first grade number sense; its predictive value was 1.1 times as large as that of attention problems (.375/.336), 2.1 times as large as executive functioning (.375/.178), and 2.3 times as large as nonverbal reasoning (.375/.163).

The MRA predicting first grade WJ applied problems scores also was significant, $R^2 = .500$, $F(9, 97) = 10.76$, $p = .001$. Two predictors made unique contributions to children's grasp of applied problems in first grade: executive functioning and attention problems. For this outcome, executive functioning made the largest unique contribution; its predictive value was 1.3 times as large as that of attention problems (.438/.349).

The MRA predicting first grade WJ calculation scores was significant, $R^2 = .572$, $F(9, 97) = 14.41$, $p = .001$. Here, attention problems, kindergarten number sense, nonverbal reasoning, executive functioning, and kindergarten start age were uniquely predictive. Attention problems made the largest unique contribution; its predictive value was 1.9 times as large as that of kindergarten number sense (.541/.281), 2.4 times as large as that of nonverbal reasoning (.541/.218), 3.3 times as large as that of executive functioning (.541/.162), and 3.6 times as large as that of kindergarten start age (.541/.150).

Finally, the MRA predicting first grade WJ reading scores was significant, $R^2 = .515$, $F(9, 97) = 11.44$, $p = .001$. Four predictors made unique contributions to children's first grade

reading performance: kindergarten number sense, kindergarten reading achievement, attention problems, nonverbal reasoning, and kindergarten start age. Kindergarten number sense, kindergarten reading, and attention problems were similarly large predictors. Executive functioning was not a significant predictor of reading when controlling for the other variables.

It is noteworthy that attention problems appear to be more important for predicting first-grade number sense and calculation performance than executive functioning while the reverse is true for first-grade applied problems. .

Mediation Analyses

Mediation models were tested separately for the first-grade outcomes variables (i.e., number sense, math computation, and applied math problems). Three models were employed to determine the indirect effects of two mediators (executive functioning and attention problems) on the relation between kindergarten number sense and first grade outcomes. Table 5 shows bootstrapped point estimates and confidence intervals from each analysis. The mediation models are displayed in Figures 1 to 3. The figures employ standardized path coefficients, where coefficients equal to .05 represent small effect sizes, .10 denotes a medium effect size, and .25 is considered to be a large effect size (Keith, 2006).

For the first-grade number sense criterion (Figure 1), the mediating effect of executive functioning was .073, $p < .05$. The effect is unique because it controls for the confound effect of attention problems. Alternatively, the unique mediating effect of attention problems was .199, $p < .01$, after controlling for the confound of executive functioning. Gender, ELL status, and Kindergarten Start Age were included as covariates, although none were statistically significant.

A similar pattern of results was observed with the WJ applied problems and WJ calculation criteria. For WJ applied problems, the mediating effect of executive functioning, controlling for attention problems, was .152, $p < .01$ (Figure 2); controlling for executive functioning, the unique mediating effect of attention problems was .156, $p < .05$. Lastly, for WJ calculation, the unique mediating effect of executive functioning, when controlling for attention problems, was .069, $p < .05$ (Figure 3). Controlling for executive functioning, the mediating effect of attention problems was .222, $p < .001$. For both WJ applied problems and WJ calculation, gender, ELL status, and Kindergarten Start Age were included as covariates, although none were statistically significant.

Across all three analyses, comparisons between the mediating effects of executive functioning vs. attention problems showed that the two variables did not significantly differ from each other on any outcome. (See table 5.)

Discussion

The robust predictive relation between kindergarten number sense and first-grade mathematics outcomes is well established (e.g., Jordan et al., 2009). Moreover, previous studies show a strong association between mathematics achievement and domain general executive functioning and attention skills (Blair & Razza, 2007; Duncan et al., 2007; Fuchs et al., 2005, 2006; Kroesbergen et al., 2009). Building on these findings, the present study demonstrates that executive functioning and attention problems, but not hyperactivity/impulsivity, make unique contributions to mathematics outcomes in first grade for at risk kindergarten children (i.e., children who start kindergarten with low number sense). Without intervention, such children with low number sense are likely to fall further behind their peers

in mathematics throughout elementary school and beyond (Fuchs, Fuchs, & Compton, 2012; Hart & Risley, 1995; Jordan et al., 2009)

Our mediation analyses demonstrated that the domain general skills of executive functioning and attention problems meaningfully contribute to the relations between kindergarten number sense and first-grade mathematics skills. Previous research has shown that socioeconomic status and early exposure to number concepts and skills are important determinants of a child's level of number sense (Clements & Sarama, 2009). Among children who enter school with relatively weak number sense, those with lower attention and/or executive functioning fare worse in first-grade mathematics than those who are stronger in these two areas. It is possible that later mathematical development is affected more heavily by individual differences in cognitive skills than is early number development, which is more affected by group factors, such as SES. Some children do not have the executive and/or attentional control to benefit optimally from the kindergarten mathematics curriculum; they are most vulnerable to the compounding effect of early learning difficulties in mathematics (Jordan et al., 2009). Children with early number sense difficulties from the start are likely to have trouble keeping pace with increasingly complex classroom instruction in mathematics and require high levels of focus and follow through on tasks (e.g., Fuchs et al., 2005, 2006; Raghubar et al., 2009); weak executive functioning and attentional skills along with low number skills then creates a cycle of failure.

Geary's (2004) model of mathematics learning is useful for interpreting the differential findings by mathematics outcome. At the broadest level, Geary's model differentiates between mathematics concepts (applied problems) and procedures (calculation). Acquisition of knowledge on any given mathematics topic requires accurate and fluent execution of procedures and concepts. Knowledge of mathematics concepts and procedures develop iteratively, such that increasing competence in one knowledge type contributes to increasing competence in the other (Rittle-Johnson & Siegler, 1998). Both attention and executive functioning support the learning of mathematics concepts and procedures, although the relative importance of each may vary with the specific skills that conceptual and procedural learning draw upon.

Our study showed that although executive functioning was important for predicting both areas of mathematics achievement assessed, it was more important for conceptual mathematics learning (applied problems) than for procedural learning (calculation) for children with low number sense. Children rely heavily on working memory, set shifting, and inhibition abilities to solve math problems (Geary, Hoard, & Hamson, 1999; Geary, 2010; Siegler, 2007). Children with limited working memory may forget which numerals have already been represented (i.e., continuing to represent the same number multiple times) or forget which operation to apply. In the process of going back to the problem to rediscover "lost" information, they can lose track of which steps in the problem-solving process have previously been completed. Children who flexibly shift between number concepts are more likely to master foundational mathematics skills more quickly (Bull & Scerif, 2001). As schooling progresses, many mathematics skills become automatized (e.g., instantaneous recall of number combinations). However, until this transition is complete, children benefit from actively using executive functioning skills (e.g., working memory and set-shifting) to derive correct solutions when problem solving (Aunola et al., 2004; Geary, et al., 2000).

Attention problems, as identified by the SWAN teacher rating scale (e.g., student makes careless mistakes), predicted all first-grade achievement outcomes, with the relation to knowledge of procedural learning (calculation) being strongest. In contrast, teacher ratings of hyperactive/impulsive behavior did not predict any academic outcomes, although this behavior was correlated with ratings of attention problems. Such a measure of classroom

attention problems was similarly predictive of math achievement outcomes in fourth grade (Jordan et al., 2013), suggesting a persistent relationship throughout elementary school. Children with problems sustaining attention may lack the ability to focus long enough on tasks and attend to relevant information to when performing mathematics procedures (Fuchs et al., 2005, 2006; Raghubar et al., 2009). Written mathematics calculation problems, as measured in the present study, require children to attend to multiple problems on the page featuring written numerals and symbols. Children need to focus on each individual problem to determine the particular procedural knowledge they need to draw upon to solve different addition and subtraction problems.

Another issue meriting discussion is the role of mediators and moderators. A mediator is a variable that suggests a potential cause and an effect, while a moderator modifies the strength and direction of a causal effect (Wu & Zumbo, 2008). Ours is the first study to use mediation analyses to explore the directional effects of potentially malleable domain general kindergarten predictors (e.g., executive functioning and attention problems) on first-grade mathematics outcomes for children with early number sense difficulties.

Our mediation analyses explored how an independent variable (kindergarten number sense) impacted dependent variables (first grade number sense, WJ applied problems, and WJ calculation) through two intermediate variables (executive functioning and attention problems), (Preacher & Hayes, 2008). Our results demonstrated that both executive functioning and attention problems mediated the relationship between kindergarten and first grade mathematics outcomes, meaning that these domain general skills play an important role in determining the relationship between kindergarten and first grade mathematics performance.

In general, background variables of gender, age, and ELL status did not make unique contributions to the mediation or regression analyses. Kindergarten start age was a significant predictor of both WJ calculation and reading in first grade ($p < .05$), although it was not significant in the mediation analyses. Although other studies also support weak or no effects of age and gender (Jordan et al., 2009), it was somewhat surprising that ELL status was not a predictor. Possibly, children's early number sense performance overrode the effects of ELL status. Supporting this observation, Jordan et al. (2009) found that kindergarten number sense mediates the relation between income level (in which ELL children are largely of low-income status) and math achievement in third grade.

A limitation of the current study is that the executive functioning measure only provided a composite score instead of separate area scores for inhibition, set shifting, and working memory. This measure did not provide the type of information with which to draw specific conclusions about the different components of executive functioning. Future studies would benefit from using a measure with separate area scores or using multiple measures to explicate the contributions of the various components of executive functioning. Another limitation was that our attention measure was a rating-based scale while the executive functioning measure was performance based. This might at least partially explain the unexpectedly weak correlation between the two measures. Finally, the generalizability of the data is limited to a restricted range (i.e., high risk children showing low number sense performance in kindergarten).

Future research should further explore the causal relationships among executive functioning, attention problems, and mathematics outcomes. Our model demonstrated that mathematics growth between kindergarten and first-grade is partially determined by cognitive skills, but more information is needed to explain the nature of this relationship. For example, a study could examine the differential effects of socioeconomic status, early exposure to

mathematics concepts and skills, and executive function and other cognitive skills on preschool versus kindergarten and first grade mathematics outcomes. Findings from such a study would address whether individual differences in cognitive skills become more important over time. Additionally, a study could investigate if children with higher executive functioning skills and fewer attention problems begin school with higher levels of number sense or if it is indeed that executive functioning and attention problems mediate the relationship between kindergarten and first grade mathematics outcomes. Such a study will require testing all cognitive ability mediators at the beginning of kindergarten or even earlier, but our study provides a starting point for investigating the differential effects of cognitive skills on mathematics outcomes for children from different ability levels. Future studies should also address specific executive functioning components related to working memory, updating, and set-shifting, as well as other basic cognitive skills, such as spatial knowledge, to illuminate further relationships among number sense, cognition, and mathematics.

By demonstrating the importance of executive functioning performance and teacher identified attention problems to mathematics outcomes for at-risk kindergartners, we provide empirical support for the development of interventions that target these skills, either through specific executive functioning interventions (e.g., Diamond & Lee, 2011) or interventions incorporated into components of mathematics instruction (Clements & Sarama, 2012). Focusing on attention and executive functioning in kindergarten and even earlier is especially important for children at high risk for academic difficulties (Clark et al., 2013). It is noteworthy that both executive functioning and classroom attention are uniquely important factors that contribute to the development of mathematics skills for children who enter kindergarten with low levels of number sense.

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Highlights

- Participants were kindergartners with low initial number sense.
- Tested how domain-general skills mediate between kindergarten and first-grade math.
- Kindergarten EF and attention problems predicted first-grade math.
- EF and attention problems mediated between kindergarten and first-grade math.
- Findings support instruction targeting EF, attention problems, and number skills.

Figure 1.

Multiple mediation model with kindergarten number sense as the predictor and first-grade number sense as the outcome. ($*p < .05$, $**p < .01$, $***p < .001$). Covariates include kindergarten start age, ELL status, and gender.

Figure 2.

Multiple mediation model with kindergarten number sense as the predictor and first-grade mathematics applied problems as the outcome ($*p < .05$, $**p < .01$, $***p < .001$). Covariates include kindergarten start age, ELL status, and gender.

Figure 3. Multiple mediation model with kindergarten number sense as the predictor and first-grade mathematics calculation as the outcome ($*p < .05$, $**p < .01$, $***p < .001$). Covariates include kindergarten start age, ELL status, and gender.

Table 1

Demographics by Group for Total Sample

	N	Gender		Ethnicity			ELL ¹	Age as of Sept 1	
		Male	Female	AA	H	C		Mean	SD
Total Sample	107	48%	52%	17%	65%	15%	57%	65.5	3.78

Note: N = Number of participants, A = African American, H = Hispanic, C = Caucasian, Other = Biracial or Asian, ELL = English-language Learners, SD = Standard Deviation, SNC = Storybook Number Competencies intervention.

¹ ELL students were identified by enrollment in bilingual classrooms.

Table 2

Means (SD) for Kindergarten and First Grade Measures

Measures	November 2011 Kindergarten	March 2012 Kindergarten	October 2012 First Grade
	Mean (SD)	Mean (SD)	Mean (SD)
Number Sense ¹	14.09 (4.23)	--	33.65 (7.29)
Reading Achievement ²	46.72 (19.80)	--	60.05 (23.10)
Executive Functioning ¹	--	49.05 (9.68)	--
Attention Problems ¹	--	-0.04 (1.00)	--
Hyperactivity/Impulsivity ¹	--	0.10 (1.02)	--
Applied Problems ²	--	--	46.44 (23.80)
Calculation ²	--	--	60.59 (30.43)
Nonverbal Reasoning ²	--	--	32.21 (21.65)

Note.

¹Raw score.²Percentile rank.

Table 3

Correlations Among All Measures

Measure	1	2	3	4	5	6	7	8	9	10
1. Number Sense (K)	1									
2. Number Sense (I)	.582**	1								
3. Reading (K)	.511**	.455**	1							
4. Reading (I)	.502**	.647**	.539**	1						
5. Executive Functioning (K)	.354**	.391**	.259**	.165	1					
6. Attention Problems (K)	.278**	.570**	.326**	.459**	.073	1				
7. Hyperactivity/Impulsivity (K)	.321***	.539**	.356**	.380**	.137	.810**	1			
8. Applied Problems (I)	.450**	.687**	.388**	.425**	.557**	.411**	.377*	1		
9. Calculation (I)	.501**	.731**	.405**	.650**	.352**	.569**	.460**	.635**	1	
10. Nonverbal Reasoning (I)	.216*	.416**	.161	.351*	.258**	.276**	.263**	.323**	.437**	1

Note. Grade administered in parentheses.

* $p < .05$,

** $p < .01$,

*** $p < .001$.

Table 4

Results of Multiple Regression for Predicting First Grade Academic Outcomes

	Number Sense	Applied Problems	Calculation	Reading
Predictor	Standardized B			
Gender	.022	-.067	.054	-.083
Kindergarten Start Age	-.104	-.088	-.150*	-.152*
ELL Status	.108	-.045	.052	.163
Attention Problems	.336**	.349**	.541***	.308*
Hyperactivity/Impulsivity	.039	-.056	-.167	-.181
Executive Functioning	.178*	.438***	.162*	-.067
Kindergarten Number Sense	.375***	.178	.281**	.358***
Kindergarten Reading	.093	.017	.078	.353***
Nonverbal Reasoning	.163*	.101	.218**	.186*
Overall <i>R</i>	.785	.707	.756	.718
<i>R</i> ²	.616	.500	.572	.515

Note.

*
 $p < .05$,**
 $p < .01$,***
 $p < .001$.

Table 5
Indirect Effects of Mediators of Kindergarten Number Sense on First Grade Outcomes

First Grade Outcomes	Mediators	Bootstrap Point Estimate	Standard Error	95% CI ²
Number Sense	Executive Functioning	.073*	.031	.024 – .154
	Attention Problems	.199**	.071	.088 – .381
Applied Problems	Executive Functioning vs. Attention Problems ¹	-.126	.080	-.318 – .008
	Executive Functioning	.152**	.054	.070 – .287
	Attention Problems	.156*	.064	.059 – .327
	Executive Functioning vs. Attention Problems ¹	-.004	.082	-.179 – .149
Calculation	Executive Functioning	.069*	.031	.020 – .143
	Attention Problems	.222***	.057	.124 – .355
	Executive Functioning vs. Attention Problems ¹	-.153	.068	-.294 – .025

Note. Mediation effects reflect indirect effects of kindergarten predictors on first grade outcomes through kindergarten mediators (executive functioning, attention problems, and number sense) following Preacher and Hayes (2008). 10000 bootstrap samples.

* $p < .05$,

** $p < .01$,

*** $p < .001$.

¹ Demonstrates whether one mediator is significantly stronger than the other.

² Bias corrected and accelerated confidence interval.