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The Relation Between Inattentive and Hyperactive/Impulsive Behaviors and Early Mathematics Skills

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Abstract

Objective: Despite strong evidence that inattentive and hyperactive/impulsive behaviors are associated with mathematical difficulties in school-age children, little research has been conducted to examine the link between these constructs before the start of formal education. The purpose of this study was to examine how different manifestations of inattentive and hyperactive/impulsive behaviors, as measured by different assessment tools, are related to early mathematics skills in preschoolers. **Method:** Eighty-two preschool children completed a measure of early mathematics and the Continuous Performance Test (CPT). Teachers rated children's behaviors using the Conners' Teacher Rating Scale–15 Item. Sixty-five of these children completed mathematics assessments 1 year later. **Results:** Teacher ratings of inattention were uniquely related to concurrent early mathematics skills, whereas CPT errors were uniquely predictive of early mathematics skills 1 year later. **Conclusion:** Findings have implications for the understanding and assessment of behavior problems that are associated with early mathematics difficulties. *(J. of Att. Dis. 2016; 20(8) 704-714)*

Keywords

early mathematics, inattention, hyperactivity/impulsivity, continuous performance test, teacher ratings

Past research has indicated that mathematics performance can be adversely impacted by a range of factors from both cognitive (Fuchs et al., 2005; Swanson & Beebe-Frankenberger, 2004; Swanson & Kim, 2007) and behavioral domains (Johnson, McGue, & Iacono, 2005; Willcutt & Pennington 2000). The early emergence of mathematical difficulties (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Starkey, Klein, & Wakeley, 2004) and the stability of those difficulties over time (B. Muthén & Khoo, 1998; Williamson, Appelbaum, & Epanchin, 1991) underscore the need to investigate factors associated with early mathematics difficulties. Such knowledge will help guide the development of early identification and intervention efforts. There is a large body of research demonstrating a link between inattentive and hyperactive/impulsive behaviors and mathematics skills across middle-childhood and adolescence. However, few studies have investigated the links between these constructs in children prior to the start of formal academic instruction. The purpose of this study was to examine the links between inattentive and hyperactive/impulsive behaviors, as measured using two different methods, and early mathematics skills in preschool children.

Mathematics Skills and Development

Mathematics skills begin to develop at an early age (Mix, 2009; National Council of Teachers of Mathematics, 2006; National Research Council, 2009; Siegler & Ramani, 2008), and evidence suggests that early mathematics skills are critical for the long-term development of later mathematics skills (Duncan et al., 2007). Some evidence suggests that children may be born with a degree of informal mathematical competence such as the ability to recognize changes in magnitude (Starkey & Cooper, 1980; Wood & Spelke, 2005). Furthermore, nearly 25% of young children are able to identify the numerals 1 to 9 before they turn 4 years old (Ginsburg & Baroody, 2003), and some young children are even able to reliably name the numerals 1 and 2

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before they turn 2 years old (Mix, 2009; Sarama & Clements, 2009). This informal knowledge develops as children explore their natural environment (Baroody & Ginsburg, 1982; Ginsburg, 1975) but can also be improved through instruction (Baroody, Eiland, & Thompson, 2009; Clements & Sarama, 2008; Starkey et al., 2004). Studies have shown that children who do not master basic addition by first grade often continue to demonstrate deficits in other aspects of basic mathematical calculations (i.e., subtraction, division, multiplication; National Mathematics Advisory Panel, 2008) and are at risk for long-term difficulties with mathematics (Ginsburg & Baroody, 1990). Although most children's mathematics skills develop typically, the development of mathematics skills for some children is delayed. The development of these children's skills is potentially hindered by an array of other factors, including behavioral problems such as inattention and hyperactivity/impulsivity (Merrell & Tymms, 2001).

Inattention, Hyperactivity/ Impulsivity, and Mathematics Skills

Inattentive and hyperactive/impulsive behaviors at clinical and subclinical levels are linked to general academic difficulties in a wide age range of children (e.g., Johnson et al., 2005; Ladd, Birch, & Buhs, 1999; Rapport, Scanlan, & Denney, 1999). Significant evidence exists linking these behaviors and reading development skills, even in children as young as preschool age (e.g., Lonigan et al., 1999; McClelland et al., 2007; Walcott, Scheemaker, & Bielski, 2010). Compared with its relation with reading difficulties, however, the relation between inattentive and hyperactive/impulsive behaviors and mathematics difficulties has been studied infrequently at younger ages (Desoete & Gregoire, 2006; Ginsburg, 1997; Hanich, Jordan, Kaplan, & Dick, 2001). In samples of elementary school children, inattention commonly co-occurs with mathematics difficulties (Benedetto-Nasho & Tannock, 1999; Marshall, Hynd, Handwerk, & Hall, 1997; Zentall, Smith, Lee, & Wieczorek, 1994) and predicts slower development of mathematical skills (Fuchs et al., 2005). Some research has indicated that inattention co-occurs more often with mathematics disability than with reading disability in school-age children (Gross-Tsur, Manor, & Shalev, 1996; Shaywitz, Fletcher, & Shaywitz, 1994).

A specific linkage between inattentive and hyperactive/impulsive behaviors and mathematics skills may exist for numerous reasons. Children with attentional problems, and younger children in general, have difficulty sustaining their attention to repetitive stimuli (Sergeant, Geurts, Huijbregts, Scheres, & Oosterlaan, 2003). The development of mathematical skills in elementary school (e.g., addition problems, multiplication problems) and preschool (e.g., counting, estimating numbers of stimuli) requires attention during learning activities and during performance tasks; therefore, children with difficulty sustaining their attention may exhibit deficits relative to their peers without attention difficulties. Inattentive children also have more difficulty than their typically developing peers ignoring irrelevant information during cognitive tasks (Marzocchi, Lucangeli, De Meo, Fini, & Cornoldi, 2002). This difficulty may interfere with performance on word problem– type tasks that require shifting through relevant and irrelevant information to determine the needed course of computational action. Slow and inaccurate performance places additional demands on executive processes, such as attention and working memory (Passolunghi, Cornoldi, & De Liberto, 1999), that are already deficient in children exhibiting inattentive and hyperactive/impulsive behaviors. Alternatively, as suggested by recent genetic research on the relation between inattention and reading skills (Cornish, Savage, Hocking, & Hollis, 2011), the link between inattention and mathematics skills may be attributed to an underlying genetic factor that influences the development of both academic skills and behavior.

The strength of the observed relation between inattentive and hyperactive/impulsive behaviors and mathematics skills may also be influenced by the method used to assess behavior problems. Several methods of assessment are utilized in the context of research and clinical practice to measure inattentive and hyperactive/impulsive behaviors. Two common assessment methods are objective cognitive tasks and rating scales completed by individuals who have regular contact with the child (e.g., classroom teachers). Objective tests, such as the Continuous Performance Test (CPT; Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956), assess children's behaviors during a specific time-limited task and do not have an inherent academic component. During this task, children view a stimulus sequence on a computer screen while responding to target stimuli and withholding responses to nontarget stimuli. Response errors are recorded in terms of omission and commission errors. An omission error occurs when the child fails to respond to a target stimulus and is presumed to indicate inattention because the child does not notice that the target stimulus has been displayed. A commission error occurs when the child responds to a nontarget stimulus and is presumed to measure hyperactivity/impulsivity because the child is either responding before confirming that the target stimulus has been displayed or is hitting the button in the context of excessive motor activity.

In contrast to time-limited objective tests, teachers are typically asked to consider the child's behavior over the course of several months when completing behavior rating scales. Certain characteristics of these scales may lead them to be stronger correlates of academic skills. For example, teacher rating scales sometimes include items that, although designed to measure behavior problems (e.g., " . . . fails to finish schoolwork"), may actually measure academic behaviors (Purpura & Lonigan, 2009). Even when completing items that do not specifically refer to academic behavior (e.g., "forgetful"), teachers may consider academically related behaviors (e.g., forgetting to turn in homework assignments) to determine their ratings. Furthermore, certain inattentive behaviors (e.g., daydreaming) may not be noticed easily unless they are accompanied by academic difficulties. Thus, teacher ratings of inattentive and hyperactive/impulsive behaviors, compared with objective measures, may yield stronger relations to early mathematics skills. However, the subjective nature of rating scales makes them prone to bias (e.g., rating the presence of behaviors that were not actually observed; Hartung et al., 2010) and issues related to interrater reliability (e.g., Collett, Ohan, & Myers, 2003). Furthermore, improvements on teacher ratings of behavior problems do not necessarily correspond to improvements in academic outcomes (DuPaul, Kern, Gormley, & Volpe, 2011).

Research with samples of younger children (e.g., preschoolers) is needed to gain a better understanding of when in development the relation of inattentive and hyperactive/impulsive behaviors with mathematical abilities emerges. This is particularly important because evidence has shown that behavioral problems may manifest in different behaviors across different ages (Gomez, 2008; Loughran, 2003; Purpura, Wilson, & Lonigan, 2010). Although several studies have established a link between inattention and early mathematics skills, these studies use measures that confound inattention with other broader executive skills (e.g., working memory; Welsh, Nix, Blair, Bierman, & Nelson, 2010) and do not examine both the unique and overlapping relations between early mathematics and different measures of inattention (Grimm, Steele, Mashburn, Burchinal, & Pianta, 2010). The lack of research on the linkage between these two areas in younger children represents a critical gap in understanding the cognitive and behavioral underpinnings of early mathematics achievement.

Summary and Purpose

Mathematics skills are linked to several areas of academic performance and general reasoning skills. The purpose of this study was to examine the overlap between inattentive and hyperactive/impulsive behaviors and early numeracy skills in preschool children, concurrently and longitudinally, using multiple methods of assessment and controlling for several other factors associated with inattentive and hyperactive/impulsive behaviors and mathematics skills including nonverbal and verbal cognitive ability (Weyandt, Mitzlaff, & Thomas, 2002), age (Lahey, Pelham, Loney, Lee, & Willcutt, 2005; Lin, Hsiao, & Chen, 1999), and gender (Gershon & Gershon, 2002; Nosek et al., 2009). Based on prior research showing that it is the inattention component, rather than the hyperactivity/impulsivity component, that accounts for the relation between ADHD and reading skills (Willcutt et al., 2007), it was hypothesized that inattention, but not hyperactivity/impulsivity, would uniquely relate to early mathematics skills. Although we used a version of the Conners' Teacher Rating Scale (CTRS; Purpura & Lonigan, 2009) that was designed to exclude academically loaded items, given that teachers may need to reference overall performance to make decisions about ratings on behavioral scales, it was hypothesized that teacher ratings of inattention would be more highly related to early mathematics skills than would be computer-administered assessments of inattention.

Method

Participants

Participants included 82 children recruited from private and public preschools in northeast Florida. All 3- to 5-year-old children at participating preschools were invited to participate in the study. Of the 82 children, 65 children completed assessments of mathematics abilities 1 year later. In terms of ethnicity, 80.2% were identified as White, 13.6% were identified as Black, and 6.2% were identified as Other race/ethnicity. This sample was approximately half (48.8%) female. Participants ranged in age from 42 to 70 months (M = 55.44 months, SD = 7.82) at the time of their first assessment.

Measures

Preschool Early Numeracy Skills (PENS) Test. The PENS test is a measure of early numeracy skills and has three different subtests: Numbering, Relations, and Arithmetic Operations. The Numbering subtest included nine tasks assessing children's ability to utilize and apply the counting sequence, as well as obtain quantity. The Relations subtest included nine tasks assessing children's skills in comparing quantities and numerals and connecting quantity to numerals. The Arithmetic Operations subtest included seven tasks assessing children's informal and formal addition and subtraction skills. More detailed descriptions and psychometric information of the measure can be found in Purpura (2010). An overall early numeracy latent factor score that subsumed the common variance from all tasks was created in Mplus Version 6.1 (L. K. Muthén & Muthén, 2010). The overall latent factor score was utilized rather than an individual score for each of the three domains because results were identical for the three factors when examined separately.

Woodcock–Johnson III Tests of Achievement. The Applied Problems and Calculation subtests of the Woodcock–Johnson III Test of Achievement (Woodcock, McGrew, & Mather, 2001) were used at Time 2. The Applied Problems subtest is an untimed mathematics test in which problems are visually and/or orally presented to the child and has been shown to have a median reliability of .85. The Calculation subtest is a paper-and-pencil arithmetic test in which children are asked to solve addition and subtraction problems and has been shown to have a median reliability of .92. Raw scores were used in all analyses.

CTRS-15 Items (CTRS-15). The CTRS-15 (Purpura & Lonigan, 2009) is a revised version of the CTRS–Revised (CTRS-R; Conners, 1997) that includes only five items corresponding to inattention and five items corresponding to hyperactivity/impulsivity. It was designed to contain only items relevant to preschool populations, and it does not include items that are primarily academic in focus (e.g., difficulty reading). The CTRS-15, although brief, has been shown to be psychometrically similar to other versions of the CTRS such as the CTRS: Revised Short Form (Conners, 1997) and the CTRS hybrid version (see Gerhardstein, Lonigan, Cukrowicz, & McGuffey, 2003). This measure also demonstrated criterion validity in that it significantly correlated with other informant report measures of ADHD. Both the inattention (α = .83) and hyperactivity/impulsivity (α = .87) subscales had good internal consistency for this sample.

CPT. The CPT (Rosvold et al., 1956) has been utilized in research as an objective measure of children's inattentive and hyperactive/impulsive behaviors. This measure is a computer-based task in which pictures of objects are flashed on a screen, and the child is asked to press a button "as fast as you can" when the target image (a fish) appears on the screen. The task comprised 220 trials including 176 that require nonresponse and 44 that require a response. Responses are recorded in terms of omission errors and commission errors. This task has been shown to have adequate test–retest reliability (average time elapsed = 4.8 months; *r*s = .65 to .74) in terms of measuring sustained attention and impulsivity (Halperin, Sharma, Greenblatt, & Schwartz, 1991). In this study, the split-half reliabilities (i.e., *r*s of omission errors and commission errors from the first and last quarter blocks of performance to the middle two quarter blocks of performance on the task) were moderate (*r*s > .80).

Nonverbal cognitive ability. The Copying subtest of the Stanford–Binet, Fourth Edition (SB-IV; Thorndike, Hagen, & Sattler, 1986) was used as a measure of nonverbal cognitive ability. This test comprised 28 items. The first 12 items require the child to duplicate the examiner's design made from blocks. The last 16 items require the child to copy designs from drawings in the administration book. This task has been shown to have adequate internal consistency (coefficients $\geq$ .81) and test–retest reliability (r = .71) for preschool children.

Verbal ability. The Definitional Vocabulary subtest of the Test of Preschool Early Literacy (TOPEL; Lonigan, Wagner, Torgesen, & Rashotte, 2007) was used as a measure of verbal ability because children's early language skills have been shown to be significantly related to their early mathematics skills (Purpura, Hume, Sims, & Lonigan, 2011). The measure includes 27 items that require the child to verbally name images of common items and provide additional information about the items (e.g., where it is found, what it is used for). The Definitional Vocabulary subtest has been shown to have high internal consistency with an alpha of .94. The test has also been shown to have good test–retest reliability (r = .81). The subtest has also been shown to have good criterion-predictive validity with a high correlation (r = .71) between the subtest and other vocabulary measures.

Procedure

The protocol was approved by the local Institutional Review Board and informed consent/permission was obtained from the parents of each participant. Teachers were asked to complete the CTRS for each participant during the course of the initial testing period. All testers were research assistants who had either completed a bachelor's degree in the social sciences or were working toward the completion of a degree. Testers were trained to administer the tasks in a standardized fashion. Testing took place in three to four separate testing sessions lasting 15 to 45 min each. Throughout testing on the mathematics measures, Copying subtest, and the Definitional Vocabulary subtest, children were given breaks if they appeared restless. Given that the CPT is designed to place demands on children's attentional capacities, research assistants were instructed not to end testing on the CPT based solely on the appearance that the child was restless.

Results

Preliminary Analyses

Descriptive statistics. Descriptive statistics for raw scores are presented in Table 1. Outliers were identified as those values outside ± 2 interquartile ranges from the mean. Outliers were corrected by changing their values to the respective limit, either two interquartile ranges above or below the mean. Generally, the correction of outliers resulted in a more conservative estimates. To reduce the influence of outliers on significance levels, all analyses reported refer to data examined with corrected outliers. There were no missing values on the Copying subtest, Definitional Vocabulary subtest, PENS test, or Woodcock–Johnson III subtests. With the exception of the Calculation subtest, all of these measures had normal distributions following the correction of outliers. Expected maximization was used for the three children who were missing data for one item on the CTRS. Even after adjusting for outliers, CTRS ratings and CPT scores were positively skewed. Square-root

Table 1. Descriptive Statistics for Behavior, Mathematics, and Cognitive Measures ($N = 82$).

Assessment tool	*M*	*SD*	Range		Skew
			Minimum	Maximum	
PENS mathematics scores Time 1	−0.07	0.86	−1.75	1.82	0.34
WJ Applied Problems Time 2[a]	18.57	5.42	1.00	30.00	−0.13
WJ Calculations Time 2[a]	3.46	4.10	0.00	16.00	1.10**
SB-IV Copying subtest	41.19	4.38	33.00	52.00	0.25
TOPEL Definitional Vocabulary	99.96	10.09	71.50	119.00	−0.47
CTRS					
Inattention	2.54	2.82	0	10.00	0.92**
Hyperactivity/impulsivity	3.34	3.33	0	12.00	0.89**
CPT					
Omission errors	15.18	11.18	0	43	0.51**
Commission errors	18.61	27.66	0	142	2.71**

Note. PENS = Preschool Early Numeracy Skills Test; WJ = Woodcock–Johnson III; SB-IV = Stanford–Binet, Fourth Edition; TOPEL = Test of Preschool Early Literacy; CTRS = Conners' Teacher Rating Scale; CPT = Continuous Performance Test. Values reported are uncorrected for skew and outliers.
[a]$n = 65$.
**$p < .05$.

transformations were used to correct for the nonnormality in the data. This technique brought the skew of CPT omission errors, Calculation subtest scores, and both CTRS subscales to a level of nonsignificance. Although the magnitude of the skew for CPT commission errors was reduced, it was still significant ($p < .01$). A series of t tests was conducted to examine the differences between boys and girls on the behavior, cognitive, and academic measures. Boys ($M = 3.87$, $SD = 2.31$) made more commission errors on the CPT than did girls ($M = 2.52$, $SD = 2.04$), $t(80) = 2.79$, $p = .007$. There were no other gender differences.

Relations between behavioral measures and mathematics scores. Partial correlations between the subscales/indices of each behavioral measure and PENS subtest controlling for age, SB-IV Copying subtest scores, TOPEL Definitional Vocabulary subtest scores, and child sex are shown in Table 2. For concurrent correlations, all measures of inattentive and hyperactive/impulsive behaviors except CPT omission errors correlated significantly with the PENS test score. For longitudinal correlations, teacher ratings were significantly correlated with Applied Problems scores. CPT errors were significantly or marginally correlated with both mathematics measure at follow-up.

Primary Analyses

To test the unique association between inattentive and hyperactive/impulsive behaviors and early mathematics skills, three mixed-effects regression analyses were conducted. The first regression was conducted to examine the unique contribution of each behavioral component (i.e., inattention and hyperactivity/impulsivity) from both methods of assessment (i.e., teacher ratings and CPT) to variance in concurrent PENS mathematics scores. The other two mixed-effect regressions were conducted to evaluate the unique association between the behavioral measures and mathematics performance 1 year later, using the two Woodcock–Johnson III subtests as the dependent measures. In all three analyses, because the intraclass correlation coefficients for school in the unconditional models indicated that school accounted for between 18% and 27% of the explained variance, children's school was included as a random effect. There were a total of 10 preschools; the number of children from the sample enrolled in each school ranged from 2 to 19. Child age, SB-IV Copying subtest scores, TOPEL Definitional Vocabulary subtest scores, and child sex were included as fixed effects covariates in all three analyses. For the two longitudinal analyses, the PENS score at Time 1 was also included as a covariate.

Concurrent relations. Results of the first analysis examining the concurrent relation between the behavior measures and mathematics performance can be found in Table 3. Overall, the full model accounted for 66% of the variance in the Time 1 PENS score. Patterns of results were similar when using the full sample of 82 children or the sample of 65 children for whom longitudinal data were collected. Teacher-rated inattention was the only behavior measure that was a significant predictor of the Time 1 PENS scores. This variable accounted for 5% unique variance in early mathematics scores when all behavior measures were included simultaneously in the model. Of the covariates, only age and language emerged as unique predictor of early mathematics skills.

Longitudinal relations. Results of the two analyses examining the predictive longitudinal relation between the behavior measures and the two measures of early mathematics skills can be found in Table 4. Overall, the full models predicting Woodcock–Johnson III Applied Problems and Calculations scores accounted for 76% and 49% of the variance, respectively. Number of CPT omission errors was the only behavior measure that was a significant unique predictor of both the WJ Applied Problems and Calculation scores when all behavior variables were included in the model simultaneously. It accounted for 2% and 3% unique variance, respectively. Of the covariates, only age and initial early mathematics skills emerged as unique predictors of scores on both mathematics subtests; language was a significant predictor of scores on the Applied Problems subtest.

Discussion

The results of this study demonstrated that inattentive behaviors are related to mathematics skills as early as the

Table 2. Partial Correlations Between Behavior Measures and Mathematics Measures Controlling for Age, Sex, Definitional Vocabulary Subtest Scores, and Stanford–Binet IV Copying Subtest Scores.

	1	2	3	4	5	6	7
1. CTRS Inattention	—	.71****	.07	.05	−.40***	−.26**	−.17
2. CTRS H/I	.71****	—	.07	.12	−.32**	−.25*	−.17
3. CPT omission errors	.06	−.07	—	−.08	−.18	−.25*	−.26**
4. CPT commission errors	.07	.11	−.01	—	−.23*	−.31**	−.24*
5. PENS mathematics scores	−.33***	−.28**	−.16	−.26**	—	.66****	.43***
6. WJ Applied Problems T2	—	—	—	—	—	—	.67****
7. WJ Calculations T2	—	—	—	—	—	—	—

Note. Values below the diagonal are for the full sample, $N = 82$. Values above diagonal are for the longitudinal sample, $n = 65$. CTRS = Conners' Teacher Rating Scale; H/I = hyperactivity/impulsivity; CPT = Continuous Performance Test; PENS = Preschool Early Numeracy Skills Test; WJ = Woodcock–Johnson III.
*$p < .10$. **$p < .05$. ***$p < .01$. ****$p < .001$.

Table 3. Mixed Effects Predicting PENS Total Standard Score From Concurrent Behavior Measures ($N = 82$).

	Concurrent sample					Longitudinal sample				
	Estimate	*SE*	Pseudo-sr^2	*F*	*p*	Estimate	*SE*	Pseudo-sr^2	*F*	*p*
Age	0.82	.21	.25	48.51	.000	0.74	.14	.22	27.82	.000
Sex	−0.19	.12	.01	2.52	.117	−0.19	.13	.01	1.90	.136
S-B Copying Subtest	0.01	.01	.00	0.93	.338	0.02	.02	.00	1.26	.252
TOPEL DV	0.02	.01	.03	7.47	.008	0.02	.01	.03	6.72	.012
CTRS H/I	−0.02	.08	.00	0.05	.832	0.03	.09	.00	0.14	.707
CTRS Inattention	−0.17	.08	.03	4.55	.036	−0.24	.09	.05	7.15	.010
CPT commission errors	−0.03	.03	.00	1.06	.306	−0.02	.03	−.01	0.44	.511
CPT omission errors	−0.06	.04	.01	3.08	.084	−0.06	.04	.00	2.29	.136

Note. PENS = Preschool Early Numeracy Skills Test; sr^2 = semipartial correlation coefficient; S-B = Stanford–Binet; TOPEL DV = Test of Preschool Early Literacy Definitional Vocabulary subtest; CTRS = Conners' Teacher Rating Scale; H/I = hyperactivity/impulsivity; CPT = Continuous Performance Test.

Table 4. Mixed Effects Predicting Follow-Up Mathematics Measures From Behavior Measures ($n = 65$).

	WJ Applied Problems				WJ Calculations			
	Estimate	*SE*	Pseudo-sr^2	*p*	Estimate	*SE*	Pseudo-sr^2	*p*
Age	1.48	.84	.00	.083	0.37	.21	.02	.085
Sex	0.71	.68	.00	.301	0.09	.17	.00	.568
S-B Copying	−0.09	.08	.00	.197	−0.02	.02	.00	.373
TOPEL DV	0.11	.03	.07	.003	−0.01	.01	.00	.381
PENS T1	3.39	.65	.11	.000	0.38	.16	.02	.023
CTRS H/I	−0.47	.45	.00	.301	−0.06	.11	−.01	.597
CTRS Inattention	0.28	.47	.00	.597	0.06	.12	−.01	.630
CPT Commissions	−0.30	.17	.01	.083	−0.04	.04	−.01	.312
CPT Omissions	−0.48	.22	.02	.031	−0.11	.05	.03	.040

Note. WJ = Woodcock–Johnson III; sr^2 = semipartial correlation coefficient; S-B = Stanford–Binet; TOPEL DV = Test of Preschool Early Literacy Definitional Vocabulary subtest; PENS = Preschool Early Numeracy Skills Test; CTRS = Conners' Teacher Rating Scale; H/I = hyperactivity/impulsivity; CPT = Continuous Performance Test.

preschool years. Similar to research on the relation between behavior problems and early reading skills of preschoolers (Willcutt et al., 2007), teacher-rated inattention was the only unique predictor of concurrent early mathematics when control variables and all other indices of inattentive and hyperactive/impulsive behaviors from both methods of assessment were included in the model. However, only CPT omission errors were unique predictors of mathematics skills 1 year later. These results imply that teacher ratings and the CPT are assessing distinct forms of behavior problems that are differentially related to early mathematics abilities. It could also be that teacher ratings are closely linked to children's concurrent mathematics skills because teacher's ratings of behavior are influenced by their knowledge of children's skill levels. Across both concurrent and longitudinal analyses, measures of inattention, but not hyperactivity/impulsivity, emerged as unique correlates of mathematics skills.

Our findings are consistent with those of studies that have examined more general executive function skills and reported relations between measures of executive functions and early mathematics skills (e.g., Blair & Razza, 2007; McClelland et al., 2007; Welsh et al., 2010). The findings of this study show that even at the preschool age, higher levels of inattentive behavior are associated with lower levels of early mathematics competence. This parallels research in populations of older children linking inattention to both lower level (e.g., addition, subtraction; Benedetto-Nasho & Tannock, 1999) and higher level conventional mathematics skills (e.g., algebraic-type word problems; Zentall et al., 1994). The relation between these two constructs in older children may exist, in part, because inattentive behaviors are already related to, and possibly influencing, the development of early mathematical skills prior to elementary school.

The results of this study are similar to others that have reported small correlations between teacher ratings of inattention and computer-based tasks presumed to measure inattention (e.g., Egeland, Johansen, & Ueland, 2009; McGee, Clark, & Symons, 2000). The finding that these two measures were also differentially related to early mathematics skills further strengthens the argument that these methods of assessment, although both associated with inattentive behaviors, are likely measuring different behavioral constructs. That is, these distinct methods of assessment may measure different aspects of attention (e.g., sustained attention vs. selective attention) or may capture different forms of behavior problems in general (e.g., the CPT may assess vigilance, whereas teacher ratings may capture elements of motivation). Further research is needed to explore the unique and overlapping correlates of each measure to gain a stronger understanding of the specific behavioral and cognitive attributes that each measure assesses.

The unique concurrent link between teacher ratings and early mathematics skills may emerge because ratings made by teachers capture classroom behaviors that relate to engagement in learning activities (e.g., listening to instructions, remembering materials, remaining seated during learning activities). Although we used a version of the CTRS that does not include items directly assessing academic ability (e.g., "difficulty in learning"), teachers may still reference academic competency when making decisions regarding the occurrence of behavior problems. For example, teachers may consider whether the child has mastered knowledge of academic material when deciding whether a child is "inattentive or easily distracted." In fact, inattention may be irrelevant or difficult to detect unless it is accompanied with co-occurring learning difficulties. Thus, the concurrent link between teacher ratings of inattentive behaviors and academic skills may be partly explained by the difficulty of operationalizing the construct of inattention without referring to other functional behaviors.

Although teacher ratings emerged as a unique concurrent predictor of early mathematics skills, number of CPT omission errors, the presumed measure of inattention on the CPT, was the only unique predictor of later mathematics skills when all behavioral measures were included in the model. This finding is in line with a study in school-age children (Biederman et al., 2004) that reported children who had a diagnosis of ADHD and performed poorly on the CPT were more likely to exhibit academic difficulties than were children who had a diagnosis but obtained typical scores on the CPT. Although teachers provide a superior snapshot of behaviors as they relate to current skill levels, the CPT may assess underlying neuropsychological deficits that are more uniquely associated with long-term learning problems and academic difficulties. Although more research is needed before clinical decisions can be based on this information, these findings suggest that each measure may play a different role in the diagnostic process. Teachers appear to be a critical source for identifying children who are exhibiting behavior problems that are associated with early academic difficulties. However, CPT performance may be more informative for long-term prognosis.

This study provides evidence that behavior problems and early mathematics skills are related in a general sample of preschool children using two methods of assessing inattentive and hyperactive/impulsive behaviors and controlling for important related factors. However, there are a few notable limitations. Due to the relatively small sample size, the results of this study should be interpreted with some caution. The small sample size precluded the ability to test gender differences and to detect small effects in the analyses. Although the dimensional conceptualization inattention and hyperactivity/impulsivity is supported (Lahey et al., 2005; Spira & Fischel, 2005), future research should include samples of children with more significant inattentive and hyperactive/impulsive behavior problems to determine whether the results of this study generalize to a more impaired sample. Furthermore, because we did not have information available regarding the diagnostic status of children (e.g., ADHD, learning disabilities) and how many children were receiving clinical services at the time of our study, we were unable to determine whether certain diagnoses or treatments may have affected the assessments of some participants. It may also be useful for future studies to include rating scales completed by parents and trained observers to see whether the associations between behavioral rating scales and early mathematics skills differ depending on the informant.

Conclusions and Implications

Although several studies have examined the differences in mathematics achievement between children with and without ADHD, this is the first study to examine specifically how inattentive and hyperactive/impulsive behaviors uniquely relate to early mathematics skills in preschool children using two different methods of assessment and examining across time. The findings imply that teachers are able to identify behavior problems that are associated with coexisting early academic performance. However, the CPT appears to be a better tool for identifying behavior problems associated with longer term difficulties with formal mathematics skills.

Although there are several well-established treatments (e.g., psychostimulant medication, behavior management strategies) that have been shown to positively impact behavior and academic productivity, these treatments appear to have limited effects on academic performance unless the intervention also contains an academic component (Benedetto-Nasho & Tannock, 1999). Such findings suggest that although these treatments improve some aspects of performance, the underlying deficits in knowledge are not easily remedied. Although problematic inattentive and hyperactive/impulsive behaviors tend to improve as children age, (Hurtig et al., 2007), the co-occurring academic deficits often persist, creating the need for intensive remedial academic-based strategies to ameliorate deficits (for review, see Loe & Feldman, 2007). This pattern underscores the need for early identification of children with behavior problems that may be at heightened risk for developing mathematics deficits.

Although it is not yet clear that behavior problems directly cause academic difficulties, early treatment at the preschool level may help improve behavior problems in a way that minimizes their potential negative impact on the development of mathematics and other academic skills. The modest correlation between CPT performance and teacher ratings of inattention, and the differential relations between these measures and early mathematics skills, imply that they are not assessing an overlapping construct. However, each measure may provide a unique opportunity to assess behavior problems that are associated with both short- and long-term academic difficulties. Further research is needed to clarify the underlying behavioral and cognitive deficits that are measured by each assessment method to guide the development of comprehensive assessments and effective interventions.

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References

Aunola, K., Leskinen, E., Lerkkanen, M., & Nurmi, J. (2004). Developmental dynamics of math performances from preschool to grade 2. *Journal of Educational Psychology*, *96*, 699-713.

Baroody, A. J., Eiland, M., & Thompson, B. (2009). Fostering at-risk preschoolers' number sense. *Early Education and Development*, *20*, 80-128.

Baroody, A. J., & Ginsburg, H. P. (1982). Preschoolers' informal mathematics skills: Research and diagnosis. *American Journal of Diseases of Children*, *136*, 195-197.

Benedetto-Nasho, E., & Tannock, R. (1999). Math computation, error patterns and stimulant effects in children with attention deficit hyperactivity disorder. *Journal of Attention Disorders*, *3*, 121-134.

Biederman, J., Monuteaux, M. C., Doyle, A. E., Seidman, L. J., Wilens, T. E., Ferrero, F., & Faraone, S. V. (2004). Impact of executive function deficits and attention-deficit/hyperactivity disorder on academic outcomes in children. *Journal of Consulting and Clinical Psychology*, *72*, 757-766.

Blair, C., & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development*, *78*, 647-663.

Clements, D. H., & Sarama, J. (2008). Experimental evaluation of the effects of a research-based preschool mathematics curriculum. *American Educational Research Journal*, *45*, 136-163.

Collett, B. R., Ohan, J. L., & Myers, K. M. (2003). Ten-year review of rating scales, V: Scales assessing attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*, *42*, 1015-1037.

Conners, K. C. (1997). *Conners' Rating Scales, Revised: User's manual*. Toronto, Ontario, Canada: Multi-Health Systems.

Cornish, K. M., Savage, R., Hocking, D. R., & Hollis, C. P. (2011). Association of the DAT1 genotype with inattentive behavior is mediated by reading ability in a general population sample. *Brain and Cognition*, *77*, 453-458.

Desoete, A., & Gregoire, J. (2006). Numerical competence in young children and in children with mathematics learning disabilities. *Learning and Individual Differences*, *16*, 351-367.

Duncan, G., Dowsett, C. J. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., & Japel, C. (2007). School readiness and later achievement. *Developmental Psychology*, *43*, 1428-1446.

DuPaul, G. J., Kern, L., Gormley, M. J., & Volpe, R. J. (2011). Early intervention for young children with ADHD: Academic outcomes for responders to behavioral treatment. *School Mental Health*, *3*, 117-126.

Egeland, J., Johansen, S. N., & Ueland, T. (2009). Differentiating between ADHD sub-types on CCPT measures of sustained attention and vigilance. *Scandinavian Journal of Psychology*, *50*, 347-354.

Fuchs, L. S., Compton, D. L., Fuchs, D., Paulsen, K., Bryant, J. D., & Hamlett, C. L. (2005). The prevention, identification, and cognitive determinants of math difficulty. *Journal of Educational Psychology*, *97*, 493-513.

Gerhardstein, R. R., Lonigan, C. J., Cukrowicz, K. C., & McGuffey, J. A. (2003). Factor structure of the Conners' Teacher Rating Scale–Short Form in a low-income preschool sample. *Journal of Psychoeducational Assessment*, *21*, 223-243.

Gershon, J., & Gershon, J. (2002). A meta-analytic review of gender differences in ADHD. *Journal of Attention Disorders*, *5*, 143-154.

Ginsburg, H. P. (1975). Young children's informal knowledge of mathematics. *Journal of Children's Mathematical Behavior*, *1*, 63-156.

Ginsburg, H. P. (1997). Mathematics learning disabilities: A view from developmental psychology. *Journal of Learning Disabilities*, *30*, 20-33.

Ginsburg, H. P., & Baroody, A. J. (1990). *Test of Early Mathematics Ability*. Austin, TX: Pro-Ed.

Ginsburg, H. P., & Baroody, A. J. (2003). *Test of early mathematics ability* (3rd ed.). Austin, TX: Pro-Ed.

Gomez, R. (2008). Item response theory analyses of the parent and teacher ratings of the *DSM-IV* ADHD Rating Scale. *Journal of Abnormal Child Psychology*, *36*, 865-885.

Grimm, K. J., Steele, J. S., Mashburn, A. J., Burchinal, M., & Pianta, R. C. (2010). Early behavioral associations of achievement trajectories. *Developmental Psychology*, *46*, 976-983.

Gross-Tsur, V., Manor, O., & Shalev, R. S. (1996). Developmental dyscalculia: Prevalence and demographic features. *Developmental Medicine & Child Neurology*, *38*, 25-33.

Halperin, J. M., Sharma, V., Greenblatt, E., & Schwartz, S. T. (1991). Assessment of the continuous performance test: Reliability and validity in a nonreferred sample. *Psychological Assessment*, *3*, 603-608.

Hanich, L. B., Jordan, N. C., Kaplan, D., & Dick, J. (2001). Performance across different areas of mathematical cognition in children with learning difficulties. *Journal of Educational Psychology*, *93*, 615-626.

Hartung, C. M., Lefler, E. K., Tempel, A. B., Armendariz, M. L., Sigel, B. A., & Little, C. S. (2010). Halo effects in ratings of ADHD and ODD: Identification of susceptible symptoms. *Journal of Psychopathology and Behavioral Assessment*, *32*, 128-137.

Hurtig, T., Ebeling, H., Taanila, A., Miettunen, J., Smalley, S. L., McGough, J. J., & Moilanen, I. K. (2007). ADHD symptoms and subtypes: Relationship between childhood and adolescent symptoms. *Journal of the American Academy of Child & Adolescent Psychiatry*, *46*, 1605-1613.

Johnson, W., McGue, M., & Iacono, W. G. (2005). Disruptive behavior and school grades: Genetic and environmental relations in 11-year-olds. *Journal of Educational Psychology*, *97*, 391-405.

Ladd, G. W., Birch, S. H., & Buhs, E. S. (1999). Children's social and scholastic lives in kindergarten: Related spheres of influence? *Child Development*, *70*, 1373-1400.

Lahey, B., Pelham, W., Loney, J., Lee, S., & Willcutt, E. (2005). Instability of the *DSM-IV* subtypes of ADHD from preschool through elementary school. *Archives of General Psychiatry*, *62*, 896-902.

Lin, C. C., Hsiao, C. K., & Chen, W. J. (1999). Development of sustained attention assessed using the continuous performance test among children 6-15 years of age. *Journal of Abnormal Child Psychology*, *27*, 403-412.

Loe, I. M., & Feldman, H. M. (2007). Academic and educational outcomes of children with ADHD. *Journal of Pediatric Psychology*, *32*, 643-654.

Lonigan, C. J., Bloomfield, B. G., Anthony, J. L., Bacon, K. D., Phillips, B. M., & Samwell, C. S. (1999). Relations among emergent literacy skills, behavior problems, and social competence in preschool children from low-and middle-income backgrounds. *Topics in Early Childhood Special Education*, *19*, 40-53.

Lonigan, C. J., Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (2007). *Test of preschool early literacy*. Austin, TX: Pro-Ed.

Loughran, S. B. (2003). Agreement and stability of teacher rating scales for assessing ADHD in preschoolers. *Early Childhood Education Journal*, *30*, 247-253.

Marshall, R. M., Hynd, G. W., Handwerk, M. J., & Hall, J. (1997). Academic underachievement in ADHD subtypes. *Journal of Learning Disabilities*, *30*, 635-642.

Marzocchi, G. M., Lucangeli, D., De Meo, T., Fini, F., & Cornoldi, C. (2002). The disturbing effect of irrelevant information on arithmetic problem solving in inattentive children. *Developmental Neuropsychology*, *21*, 73-92.

McClelland, M. M., Cameron, C. E., Connor, C. M., Farris, C. L., Jewkes, A. M., & Morrison, F. J. (2007). Links between behavioral regulation and preschoolers literacy, vocabulary, and math skills. *Developmental Psychology*, *43*, 947-959.

McGee, R. A., Clark, S. E., & Symons, D. K. (2000). Does the Conners' Continuous Performance Test aid in ADHD diagnosis? *Journal of Abnormal Child Psychology*, *28*, 415-424.

Merrell, C., & Tymms, P. B. (2001). Inattention, hyperactivity and impulsiveness: Their impact on academic achievement and progress. *British Journal of Educational Psychology*, *71*, 43-56.

Mix, K. S. (2009). How Spencer made number: First uses of the number words. *Journal of Experimental Child Psychology*, *102*, 427-444.

Muthén, B., & Khoo, S. T. (1998). Longitudinal studies of achievement growth using latent variable modeling. *Learning and Individual Differences*, *10*, 73-101.

Muthén, L. K., & Muthén, B. O. (2010). *Mplus 6.1 [Computer program]*. Los Angeles, CA: Author.

National Council of Teachers of Mathematics. (2006). *Curriculum focal points for prekindergarten through Grade 8 mathematics*. Reston, VA: Author.

National Mathematics Advisory Panel. (2008). *Foundations for success: The final report of the National Mathematics Advisory Panel*. Washington, DC: U.S. Department of Education.

National Research Council. (2009). Mathematics learning in early childhood: Paths toward excellence and equity. Committee on Early Childhood Mathematics. In C. T. Cross, T. A. Woods, & H. Schweingruber (Eds.), *Center for education, division of behavioral and social sciences and education*. Washington, DC: National Research Academies Press.

Nosek, B. A., Smyth, F. L., Sriram, N., Lindner, N. M., Devos, T., Ayala, A., & Greenwald, A. G. (2009). National differences in gender-science stereotypes predict national sex differences in science and math achievement. *Proceedings of the National Sciences of the United States of America*, *106*, 10593-10597.

Passolunghi, M. C., Cornoldi, C., & De Liberto, S. (1999). Working memory and intrusions of irrelevant information in a group of specific poor problem solvers. *Memory & Cognition*, *27*, 779-790.

Purpura, D. J. (2010). Informal *number-related mathematics skills: An examination of the structure of and relations between these skills in preschool* (Doctoral dissertation). Available from ProQuest Dissertations and Theses. (Accession Order No. AAT 3462344)

Purpura, D. J., Hume, L., Sims, D., & Lonigan, C. J. (2011). Emergent Literacy and Mathematics: The value of including emergent literacy skills in the prediction of mathematics development. *Journal of Experimental Child Psychology*, *110*, 647-658.

Purpura, D. J., & Lonigan, C. J. (2009). Conners' teacher rating scale for preschool children: A revised, brief, age-specific measure. *Journal of Clinical Child & Adolescent Psychology*, *38*, 263-272.

Purpura, D. J., Wilson, S. B., & Lonigan, C. J. (2010). ADHD symptoms in preschool children: Examining psychometric properties using IRT. *Psychological Assessment*, *22*, 546-558.

Rapport, M. D., Scanlan, S. W., & Denney, C. B. (1999). Attention-deficit/hyperactivity disorder and scholastic achievement: A model of dual developmental pathways. *Journal of Child Psychology and Psychiatry*, *40*, 1169-1183.

Rosvold, H. E., Mirsky, A. F., Sarason, I., Bransome, E. D., & Beck, L. H. (1956). A continuous performance test of brain damage. *Journal of Consulting Psychology*, *20*, 343-350.

Sarama, J., & Clements, D. H. (2009). *Early childhood mathematics education research: Learning trajectories for young children*. New York, NY: Routledge.

Sergeant, J. A., Geurts, H., Huijbregts, S., Scheres, A., & Oosterlaan, J. (2003). The top and bottom of ADHD: A neuropsychological perspective. *Neuroscience & Biobehavioral Reviews*, *27*, 583-592.

Shaywitz, S. E., Fletcher, J. M., & Shaywitz, B. A. (1994). Issues in the definition and classification of attention deficit disorder. *Topics in Language Disorders*, *14*, 1-25.

Siegler, R. S., & Ramani, G. B. (2008). Playing linear numerical board games promotes low-income children's numerical development. *Developmental Science*, *11*, 655-661.

Spira, E. G., & Fischel, J. E. (2005). The impact of preschool inattention, hyperactivity, and impulsivity on social and academic development: A review. *Journal of Child Psychology and Psychiatry*, *46*, 755-773.

Starkey, P., & Cooper, R. G. (1980). Perception of numbers by human infants. *Science*, *210*, 1033-1035.

Starkey, P., Klein, A., & Wakeley, A. (2004). Enhancing young children's mathematical knowledge through a pre-kindergarten mathematics intervention. *Early Childhood Research Quarterly*, *19*, 99-120.

Swanson, H. L., & Beebe-Frankenberger, M. (2004). The relationship between working memory and mathematical problem solving in children at risk and not at risk for serious math difficulties. *Journal of Educational Psychology*, *96*, 471-491.

Swanson, H. L., & Kim, K. (2007). Working memory, short-term memory, and naming speed as predictors of children's mathematical performance. *Intelligence*, *35*, 151-168.

Thorndike, R. L., Hagen, E. P., & Sattler, J. M. (1986). *The Stanford–Binet Intelligence Scale: Guide for administering and scoring*. Chicago IL: Riverside Publishing.

Walcott, C. M., Scheemaker, A., & Bielski, K. (2010). A longitudinal investigation of inattention and preliteracy development. *Journal of Attention Disorders*, *14*, 79-85.

Welsh, J. A., Nix, R. L., Blair, C., Bierman, K. L., & Nelson, K. E. (2010). The development of cognitive skills and gains in academic school readiness for children from low-income families. *Journal of Educational Psychology*, *102*, 43-53.

Weyandt, L. L., Mitzlaff, L., & Thomas, L. (2002). The relationship between intelligence and performance on the test of variables of attention (TOVA). *Journal of Learning Disabilities*, *35*, 114-120.

Willcutt, E. G., Betjemann, R. S., Wadsworth, S. J., Samuelsson, S., Corley, R., Defries, J. C., & Olson, R. K. (2007). Preschool twin study of the relation between attention-deficit/hyperactivity disorder and prereading skills. *Reading and Writing*, *20*, 103-125.

Willcutt, E. G., & Pennington, B. F. (2000). Comorbidity of reading disability and attention-deficit/hyperactivity disorder: Differences by gender and subtype. *Journal of Learning Disabilities*, *33*, 179-191.

Williamson, G. L., Appelbaum, M., & Epanchin, A. (1991). Longitudinal analyses of academic achievement. *Journal of Educational Measurement*, *28*, 61-76.

Wood, J. N., & Spelke, E. S. (2005). Infants' enumeration of actions: Numerical discrimination and its signature limits. *Developmental Science*, *8*, 173-181.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock–Johnson III*. Itasca, IL: Riverside Publishing.

Zentall, S. S., Smith, Y. N., Lee, Y. B., & Wieczorek, C. (1994). Mathematical outcomes of attention-deficit hyperactivity disorder. *Journal of Learning Disabilities*, *27*, 510-519.

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