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Kindergarten Children's Executive Functions Predict Their Second-Grade Academic Achievement and Behavior

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Whether and to what extent kindergarten children's executive functions (EF) constitute promising targets of early intervention is currently unclear. This study examined whether kindergarten children's EF predicted their second-grade academic achievement and behavior. This was done using (a) a longitudinal and nationally representative sample (N = 8,920, M_{age} = 97.6 months), (b) multiple measures of EF, academic achievement, and behavior, and (c) extensive statistical control including for domain-specific and domain-general lagged dependent variables. All three measures of EF—working memory, cognitive flexibility, and inhibitory control—positively and significantly predicted reading, mathematics, and science achievement. In addition, inhibitory control negatively predicted both externalizing and internalizing problem behaviors. Children's EF constitute promising targets of experimentally evaluated interventions for increasing academic and behavioral functioning.

Executive functions (EF) are cognitive processes hypothesized to contribute to academic achievement and classroom behavior by helping children control and coordinate their goal-directed behaviors through planning, reasoning, organization, regulation, and information integration (e.g., Best, Miller, & Naglieri, 2011; Blair & Raver, 2014, 2015). Children's EF may begin as a general factor prior to age 3 and then differentiate into specific and coordinated processes by age 5, which may or may not be subordinated by subsequent growth in their selective attention capacity (Garon, Bryson, & Smith, 2008). Three specific EF hypothesized to contribute to children's early academic achievement and classroom behavior are as follows: (a) *working memory*, or the ability to hold and manipulate information during a brief time; (b) *cognitive flexibility*, or the ability to shift attention among distinct but related aspects of a task as well as adapt responses using new information; and (c) *inhibitory control*, or the ability to delay or inhibit some initial response while attempting to complete a task requiring goal-directed behavior (Cantin, Gnaedinger, Gallaway, Hesson-McInnis, & Hund, 2016; Diamond, 2012; Monette, Bigras, & Lafrenière, 2015).

Hypothesized Contributions of EF to Achievement and Behavior

These three EF may contribute to academic achievement and behavior by facilitating children's organization and self-regulation. Working memory may help children manage information maintenance and processing demands while avoiding information loss due to forgetfulness and distraction (Jarrold & Towse, 2006). Cognitive flexibility may help children attend to changing meaning in texts, incorporate additional knowledge, and simultaneously disregard or update previously used knowledge (Yeniad, Malda, Mesman, van IJzendoorn, & Pieper, 2013). Inhibitory control may help children ignore impulsive responses and remain

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engaged during classroom instruction and activities (Allan, Hume, Allan, Farrington, & Lonigan, 2014; Berry, 2012). These organizational and regulatory EF may be especially useful when completing a classroom's novel or demanding tasks.

Elementary school classroom environments place heavy demands on children's EF by frequently introducing new procedures, observations, evidence, and rules that require higher order thinking, often simultaneously (Clements, Sarama, & Germeroth, 2016; Gropen, Clark-Chiarelli, Hoisington, & Ehrlich, 2011). Children with well-developed EF should be better able to plan, maintain attention, remember, and apply a teacher's instruction while completing multiple classroom tasks. This should facilitate children's ability to benefit from both informal and formal learning opportunities and so result in better academic achievement and classroom behavior (Bull, Espy, & Wiebe, 2008; Clements et al., 2016; Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013; Laski & Dulaney, 2015; Nayfeld, Fuccillo, & Greenfield, 2013). In contrast, children with less-developed EF tend to struggle to organize and regulate their learning and behavior (Geary, Hoard, Nugent, & Bailey, 2012). Consequently, EF may constitute potential targets of early interventions for closing achievement gaps (Blair & Raver, 2014; Diamond & Lee, 2011; Gropen et al., 2011; Morgan et al., 2016; Viterbori, Usai, Traverso, & De Franchis, 2015) and for increasing educational opportunities and subsequent well-being (Moffitt et al., 2011). Children's EF are considered "inherently malleable" through school-based interventions (Blair, 2016, p. 3). For example, interventions that increase working memory may help children academically by facilitating their ability to make and then manipulate mental representations (e.g., making inferences, using mental number lines, understanding place value), thereby leading to better comprehension, fewer errors when solving problems involving counting or computation, and better strategic rule use (Nutley & Soderqvist, 2017).

Current Limitations in the Field's Knowledge Base

Yet recently identified limitations in the field's knowledge base have led to debate over whether and to what extent EF should be viewed as promising targets of school-based intervention efforts including for children at risk for experiencing academic and behavioral difficulties (Clements et al., 2016; Jacob & Parkinson, 2015). Although EF are repeatedly associated with academic and behavioral functioning, existing research has also been characterized as offering "no compelling evidence" that the associations are causal (Jacob & Parkinson, 2015, p. 512) and that "the causal evidence that interventions to develop EF will increase achievement is weak" (Clements et al., 2016, p. 86). For example, Willoughby, Kupersmidt, and Voegler-Lee's (2012) fixed effects analyses yielded no quasi-experimental evidence that EF was causally related to children's achievement. Limitations in the available experimental studies have resulted in ambiguity regarding whether EF training increases academic achievement (Jacob & Parkinson, 2015; Kirk, Gray, Riby, & Cornish, 2015; Rapport, Orban, Kofler, & Friedman, 2013; Titz & Karbach, 2014).

The existing correlational work has also been identified as having limitations that constrain the field's knowledge base (Jacob & Parkinson, 2015). Methodological limitations include the use of cross-sectional designs and analyses that do not account for confounding factors that may instead explain initially observed associations between EF and academic achievement or behavior (Jacob & Parkinson, 2015). Potential confounds include sociodemographic characteristics (e.g., family socioeconomic status [SES], gender, age, race/ethnicity, disability status; Friso-van den Bos et al., 2013; Jacob & Parkinson, 2015). Prior academic and behavioral functioning and family SES are considered especially strong confounds (Jacob & Parkinson, 2015) that may fully explain observed associations between EF and children's achievement and behavior (Willoughby et al., 2012). Although some multivariate longitudinal studies have controlled for earlier achievement when examining EF's predictive relations with later achievement, this has often been done using domain-specific but not domain-general independent variables (e.g., controlling for reading but not also mathematics achievement when estimating predictive relations between EF and reading achievement).

Yet statistical control for domain-specific lagged dependent variables may not sufficiently control for the strong confound of prior achievement. This is because domain-specific achievement is known to be strongly predicted by both domain-specific and domain-general achievement (Morgan, Farkas, Hillemeier, & Maczuga, 2016; Morgan, Farkas, & Wu, 2011). For example, early mathematics achievement predicts later reading achievement as strongly or more strongly than early reading achievement (Duncan et al., 2007). Similarly, children's behavior can predict their achievement (e.g., Duncan et al., 2007) and may also mediate initially observed relations between EF and achievement (Baptista, Osório, Martins, Verissimo, & Martins, 2016; Vitiello, Greenfield, Munis, & George, 2011). Yet behavior has only occasionally been included as a potential confound when examining predictive relations with specific EF processes (McClelland et al., 2014). Establishing that EF (a) temporally precede academic achievement and classroom behavior and (b) remain predictive of both aspects of children's development even following control for the strong confounds of domain-general achievement and domain-general behavior as well as additional background characteristics would provide rigorous evidence for these relations as *potentially* causal (Jacob & Parkinson, 2015; Murname & Willett, 2011). Doing so should help clarify whether and to what extent EF should be viewed as promising targets of experimentally-evaluated interventions for children at risk of experiencing academic or behavioral difficulties during elementary school.

Additional limitations also characterize the field's existing correlational knowledge base. To date, relatively few studies, including those using designs that account for potential confounds, have directly contrasted multiple subcomponents of EF in the analyses (Jacob & Parkinson, 2015; Schmitt, Geldhof, Purpura, Duncan, & Mcclelland, 2017). Thus, it is unclear which of the specific EF subcomponents (e.g., working memory vs. cognitive flexibility vs. inhibitory control) constitute comparatively more promising intervention targets (Berry, 2012; Bull & Lee, 2014; Cartwright et al., 2017; Fitzpatrick & Pagani, 2012; Jacob & Parkinson, 2015; Ropovik, 2014). Working memory is thought to be directly involved in facilitating school-aged children's problem solving, strategic thinking, and higher order learning (Ropovik, 2014). Because children with greater working memory capacities should be able to better meet the continual storage and processing demands of classroom environments, they should be better able to problem solve and engage in higher order learning activities that become increasingly common throughout the primary grades. For instance, children with greater working memory capacities should be better able to comprehend text or solve problems, follow multistep instructions, and select and then use effective learning strategies (Viterbori et al., 2015). These children should therefore be less likely to struggle academically and so be more attentive and engaged in their classrooms and less likely to display acting out or withdrawn behaviors (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Gathercole et al., 2008). Working memory's domain-general relations with achievement have been reported to persist over time (Bull et al., 2008) including during the elementary grades (Stipek & Valentino, 2015; Viterbori et al., 2015).

Cognitive flexibility and inhibitory control have also been theorized and found to be positively related to children's achievement and behavior. This is because each of these EF may facilitate children's ability to shift attention across multiple aspects of tasks (e.g., incorporating new information about a character or story plot or using addition, subtraction, and multiplication strategies to complete a multistep word problem) including those involving problem solving, hypothesis generation, and strategic rule use (Cartwright et al., 2017; Nayfeld et al., 2013; Yeniad et al., 2013). In addition, both inhibitory control and cognitive flexibility may exhibit domain-general relations with achievement and behavior by facilitating children's ability to disregard irrelevant information (Laski & Dulaney, 2015) and their ability to downregulate disruptive, aggressive, or withdrawal impulses (Berry, 2012; Cain, 2006). Inhibitory control predicts children's analogical reasoning development at age 15 even after controls for attention, short-term memory, vocabulary, and other types of EF (Richard & Burchinal, 2013).

Thus, failing to simultaneously estimate the predictive relations of multiple components of EF may have led to spurious estimates of any single component's domain-general or domain-specific relations with academic achievement or classroom behavior. For example, observed associations between cognitive flexibility or inhibitory control and academic achievement may be explained by the lack of control for working memory (Bull & Lee, 2014; Ropovik, 2014; Viterbori et al., 2015). To date, no studies have simultaneously examined whether specific types of EF are related to academic achievement in reading, mathematics, and science, as well as classroom behavior after accounting for the strong confounds of lagged-dependent domain-general measures of academic and behavioral functioning (Fuhs, Nesbitt, Farran, & Dong, 2014; Jacob & Parkinson, 2015; Schmitt et al., 2017; Willoughby et al., 2012). Independent predictive relations between working memory, cognitive flexibility, or inhibitory control and children's academic achievement have been hypothesized to only occur as children age (e.g., adolescence) following greater EF differentiation (Bull & Lee, 2014; Seigneuric & Ehrlich, 2005). Alternatively, it may be that sampling and measurement limitations have obscured these relations during the primary grades, particularly for cognitive flexibility and inhibitory control. It also may be that the potential contributions of children's cognitive flexibility and inhibitory control to their academic achievement and classroom behavior have not been observed during these grades because most studies have analyzed preschool-aged samples and so at time periods when these two types of EF are relatively less developed and less taxed as cognitive processes in classroom environments. Children's EF grows substantially during elementary school (Yeniad et al., 2014).

Thus, it remains to be empirically established whether working memory, cognitive flexibility, and inhibitory control contribute more strongly and differentially to domain-general versus domain-specific types of achievement and behavior, particularly as assessed in a longitudinal and nationally representative sample of children progressing through the primary grades in U.S. elementary schools. Instead, most studies have analyzed comparatively smaller and less diverse samples of children (Fuhs et al., 2014; Vitiello et al., 2011), including well-designed studies accounting for potential confounds (McClelland et al., 2014; Schmitt et al., 2017; Willoughby et al., 2012). This has limited the generalizability of the available findings. For example, Jacob and Parkinson's (2015) synthesis of 67 EF studies reported an average sample size of 237, with many studies analyzing samples of 40 or 50 typically developing children. Other studies have analyzed somewhat larger but also mostly at-risk samples of children (e.g., McClelland et al., 2014). Analyses of a diverse and nationally representative sample of U.S. schoolchildren followed over the primary grades should clarify the predictive relations between early EF and later academic achievement and behavior, with the findings generalizable to the U.S. school-aged population.

Study's Purpose

We investigated whether and to what extent kindergarten children's EF predict their second-grade academic achievement and classroom behavior, and so might constitute potential targets of experimentally evaluated early intervention efforts. To address recently identified methodological and substantive limitations in the field's correlational knowledge base (Jacob & Parkinson, 2015), we analyzed multiyear data from a nationally representative sample of U.S. schoolchildren whose EF, academic achievement, and classroom behavior were individually assessed using multiple, psychometrically strong, and standardized measures, including three types of academic achievement (i.e., reading, mathematics, and science achievement) and two types of classroom behavior (i.e., externalizing and internalizing problem behaviors). We designed the study to investigate the following research questions:

1. Do each of the three specific types of EF (i.e., working memory, cognitive flexibility, and inhibitory control) in kindergarten predict children's achievement and behavior in second grade despite statistical control for strong potential confounds, including kindergarten measures of academic achievement, oral vocabulary knowledge, classroom behavior problems, and sociodemographic as well as other background characteristics?
2. After controlling for potential confounds, are there domain-general and domain-specific predictive relations between children's (a) working memory, cognitive flexibility, and inhibitory control in kindergarten and (b) academic achievement and classroom behavior in second grade? Does each of these three types of EF predict children's school functioning, even after controls for the other types of EF? Which types of EF in kindergarten most consistently predict children's achievement and behavior in second grade?

Method

Data set and Analytical Sample

We analyzed the restricted version of the nationally representative Early Childhood Longitudinal Study, Kindergarten Class of 2011 (ECLS-K: 2011) data set. The ECLS-K: 2011 is maintained by the National Center for Educational Statistics (NCES), Institute of Education Sciences of the U.S. Department of Education. Currently available data were collected in the fall of 2010, fall and spring of 2011, fall and spring of 2012, and spring of 2013. These dates generally corresponded to children's enrollment in kindergarten, first grade, and second grade. NCES provided sampling weights, which were necessary to account for the ECLS-K: 2011's complex study design. Our analytic sample consisted of 8,920 children (with sample sizes rounded to the nearest 10, per NCES confidentiality requirements), including 500 cases for which missing values on one or more predictor variables were imputed using standard multiple imputation techniques (i.e., use of IVEWARE software (Survey Research Center, Institute for Social Research, Ann Arbor, MI) to yield five imputed data sets). As a robustness check, we also analyzed a larger sample of 12,300 children that we could obtain by ignoring the absence of sampling weights for some cases and still use multiple imputations. We then repeated our regression analyses with this larger sample, but without adjusting for the complex sample design because weights were not available for all cases. The results were quite similar to those reported here and are available from the study's first author. Table 1 displays the analytical sample's descriptive statistics. The analytical sample of 8,920 children was diverse and representative with regard to race and ethnicity, gender, family SES, and additional characteristics.

Table 1
Descriptive Statistics of Selected Variables (N = *8,920)*

Variable	*M* or proportion (*SD*)
Executive functions	
Working memory, spring kindergarten	15.2 (2.7)
Cognitive flexibility, spring kindergarten	451.2 (30.1)
Inhibitory control, spring kindergarten	5.1 (1.3)
Sociodemographic characteristics	
White	52.1%
Black	13.4%
Hispanic	24.3%
Asian	4.5%
Other race/ethnicity	5.6%
Female	48.6%
Lowest SES quintile, kindergarten	21.0%
Second lowest SES quintile, kindergarten	24.2%
Middle SES quintile, kindergarten	23.2%
Second highest SES quintile, kindergarten	16.5%
Highest SES quintile, kindergarten	15.1%
Non-English used at home, spring kindergarten	16.2%
IEP, spring second grade	11.1%
Age (in months), spring second grade	97.6 (4.4)
Academic achievement	
Reading achievement, spring kindergarten	0.6 (0.7)
Mathematics achievement, spring kindergarten	0.5 (0.6)
Science achievement, spring kindergarten	0.2 (0.6)
Vocabulary, spring kindergarten	19.2 (2.1)
Reading achievement, spring second grade	2.1 (0.6)
Mathematics achievement, spring second grade	2.5 (0.8)
Science achievement, spring second grade	1.6 (0.9)
Behavioral functioning	
Externalizing problem behaviors, spring kindergarten	1.6 (0.6)
Internalizing problem behaviors, spring kindergarten	1.5 (0.5)
Externalizing problem behaviors, spring second grade	1.7 (0.6)
Internalizing problem behaviors, spring second grade	1.6 (0.5)

Note. N rounded to nearest 10. Continuous variables standardized. Sampling weights used. IEP = individualized educational program; SES = socioeconomic status.

Measures

Reading, Mathematics, and Science Achievement

Field staff from NCES individually administered untimed, item response theory-scaled reading, mathematics, and science assessments that displayed good psychometric properties (Tourangeau et al., 2015). The validity of the achievement assessments was determined by the ECLS-K: 2011 project staff based on a review of national and state performance standards, comparison with state and commercial assessments, and judgments from curriculum experts (Tourangeau et al., 2015). The 2009 National Assessment of Educational Progress (NAEP) Reading Frameworks, 1996 NAEP Mathematics Frameworks, and 2009 science achievement standards published by six states (i.e., Arizona, California, Florida, New Mexico, Texas, and Virginia) were used to design the ECLS-K: 2011's achievement measures. The reading achievement assessments contained items relating to: (a) basic skills (i.e., print familiarity, letter recognition, beginning and ending sounds, sight vocabulary, and recognizing common words); (b) vocabulary knowledge (including receptive vocabulary and vocabulary in context); and (c) reading comprehension. The mathematics achievement assessments contained items relating to procedural and conceptual knowledge as well as problem solving. Additional content included (a) number sense and number properties; (b) basic mathematical operations; (c) measurement; geometry and spatial sense; (d) data analysis, statistics, and probability; and (e) patterns, algebra, and functions. The science achievement assessments included items related to (a) physical sciences; (b) life sciences; (c) environmental sciences; and (d) scientific inquiry. We analyzed scores from the spring of kindergarten and second-grade administrations of these assessments.

During kindergarten and second grade, the reading, mathematics, and science assessments were administered during one session. The items for each assessment were administered in two stages. The first stage consisted of items of varying degrees of difficulty. Performance on those items routed children to 1 of 3 second-stage tests—low, medium, or high difficulty. The number of items in the first stage was 29 for reading, 19 for science, and 20 for mathematics. The total number of items administered varied depending on which second-stage assessment was administered. The average time spent completing the measures of achievement was 58 min per child (Tourangeau et al., 2015). Theta reliabilities for the ECLS-K: 2011's reading, mathematics, and science assessments in kindergarten and second grade were relatively high. In the kindergarten wave, theta scores were .95 for reading, .94 for mathematics, and .75 for science. In second grade, the scores were .91 for reading, .94 for mathematics, and .83 for science.

Regardless of primary language, all children completed the first two items of the Preschool Language Assessment Scale (*pre*LAS 2000) in English as a language screener. The children also received the first set of 18 items in the reading assessment in English. This served as the routing portion of the two-stage reading assessment. Children who passed the screener were then routed to the second stage of the reading assessment in English. They then completed the other assessments that were also administered in English. Spanish-speaking children who failed the English language screener were routed to the Spanish Early Reading Skills assessment and then onto mathematics and executive functioning assessments that had been translated into Spanish. Children who failed the screener and did not speak Spanish received only the first set of reading assessment items.

Vocabulary

We statistically controlled for children's oral vocabularies. Two tasks from the *pre*LAS were administered during kindergarten to assess children's oral vocabularies. One was the "Simon Says" task that required children to follow an assessor's simple and direct instructions. The other was the "Art Show" task that was a picture vocabulary assessment designed to measure children's expressive vocabulary. These two tasks were used as a language screener in the ECLS-K: 2011. The tasks are considered valid and reliable (Rainelli, Bulotsky-Shearer, Fernandez, Greenfield, & López, 2017). Cronbach's alphas are high for both "Simon Says" (.88) and "Art Show" (.90; Duncan & De Avila, 1998). Possible values ranged from 2 to 20 on this oral vocabulary measure. This variable's distribution showed a pile-up of values at 20 (i.e., a perfect score), with a long-left tail. Accordingly, and for analytical purposes, we used dummy variables with a score below 12 being the base category, and separate dummies for each of the score ranges 12–15, 16–19, and 20.

Executive Functioning

Working memory. Kindergarten children's working memory was individually assessed using the Numbers Reversed subtest of the Woodcock–Johnson III Tests of Cognitive Abilities (Woodcock, McGrew, & Mather, 2001). Reliability coefficients for the Numbers Reversed subtest are about .90 (Schrank, 2011). The assessment had children repeat sets of single-digit numbers in reverse order. For example, if the test administrator presented the numbers "3, 5, 7," children were correct if they answered "7, 5, 3." Participating children were first given 5 two-digit sequences. Testing was stopped following three consecutive incorrect answers. Otherwise, children were then given 5 three-digit sequences. The procedure was repeated with progressively longer sequences (to a maximum of eight digits) until three consecutive sequences were answered incorrectly. Responses were coded as "correct," "incorrect," or "not administered." Scores were recoded into *W* scores as recommended by the measure's publishers. The *W* scale is a standardized scale that has a mean of 500 and a standard deviation of 100.

Cognitive flexibility. Kindergarten children's cognitive flexibility was individually measured using the Dimensional Change Card Sort (DCCS). The DCCS displays both construct and discriminatory validity (Zelazo et al., 2013). The task required children to sort 22 different picture cards on the basis of different rules. Each card had a picture of either a red rabbit or a blue boat. Children were asked to sort each of the 22 cards using a sorting rule (either by color or by shape). Children were given four cards as a practice task and then the DCCS was administered. The task was presented as a game. Children first played the Color game (i.e., sort by color) and then the Shape game (i.e., sort by shape). Those who played well enough on the Shape game (i.e., sorted four of six cards correctly) were then asked to play the Border game in which cards were sorted based on whether they had a black border. Children were asked to sort cards with black borders by color and cards without black borders by shape. The DCCS has strong test–retest reliabilities with correlations generally ranging from .90 to .94. In administering the working memory and cognitive flexibility assessments, children completed the DCCS first with the sorting rules intermixed within this task. The Numbers Reversed task was administered following the DCCS. The total time required for completion of these two EF assessments averaged 10 min.

Inhibitory control. Kindergarten children's inhibitory control was individually measured using the Children's Behavior Questionnaire (Putnam & Rothbart, 2006). During the spring of kindergarten, teachers rated how often individual children demonstrated social behaviors related to attention and inhibitory control. The inhibitory control subscale consisted of six items that examined how children reacted to different situations in the past 6 months. For instance, teachers were asked to rate whether the children were easily distracted when listening to a story and could easily stop an activity when told "no." For each scenario, teachers reported on a 7-point scale from "extremely untrue" to "extremely true." The internal consistency reliability coefficient for the inhibitory control scale was .87. Allan et al.'s (2014) meta-analysis identified teacher ratings on questionnaires as a preferred type of measure when examining how inhibitory control related to young children's academic achievement.

Behavioral Functioning

The ECLS-K: 2011 used a modified version of the psychometrically validated Social Skills Rating System (Gresham & Elliott, 1990) to measure children's classroom behaviors. We used kindergarten measures of children's externalizing and internalizing problem behaviors as predictors in all regressions and second-grade measures of these variables as outcomes. Kindergarten and second-grade teachers rated the children's externalizing and internalizing problem behaviors in the spring. The Internalizing Problem Behaviors subscale consisted of four items (i.e., is the child lonely, sad, anxious, or displayed low self-esteem), while the Externalizing Problem Behaviors subscale consisted of five items (i.e., arguing, fighting, acting impulsively, getting angry, disturbing activities). For each subscale, teachers rated children's behavior on a 4-point scale from "never" to "very often." Higher scores indicated that the behavior occurred more frequently. The internal consistency reliability coefficients for the internalizing and externalizing problem behaviors scales ranged from .78 to .91.

Sociodemographic Characteristics

Parents identified their child's gender, age (in months), race or ethnicity, and whether the primary language spoken at home was a language other than English. The child's race or ethnicity was reported in one of the following categories: White, non-Hispanic; Black, non-Hispanic; Hispanic; Asian; or Other. Family SES was indicated by a composite of survey items about each parent's or guardian's education level and occupation as well as the household's income. We divided SES into quintiles to allow for nonlinear effects. Children's disability status was indicated by whether special education teachers reported an individualized education program (IEP) was on file at the school. We adjusted for age of testing at second grade.

Data Analysis

We analyzed the data using ordinary linear regression (OLS) models with lagged dependent variables. All continuous variables were standardized prior to the regression analysis. Robust standard errors (clustered on the kindergarten school attended by the child) were computed. We predicted second-grade children's scores on three independently administered academic achievement measures and two teacher-rated behavioral scales using three indicators of their EF in kindergarten while simultaneously controlling for potentially confounding domain-general achievement and behavior in kindergarten and sociodemographic characteristics. All analyses were performed with SAS Version 9.3 (SAS Institute Inc., Cary, NC). We used standard alpha levels (i.e., $p < .05$, .01, and .001) and reported the covariate-adjusted effect sizes (ES) in standard deviation units to facilitate relative strength-of-effect contrasts.

Equation (1) shows the form of the estimated equations (one for each of the study's five dependent variables):

$$\begin{aligned} Y(t=2) = b_0 + b_1 Y(t=0) + b_2\mathrm{WM}(t=0) \\ + b_3\mathrm{CF}(t=0) + b_4\mathrm{IC}(t=0) \\ + b_5\mathrm{controls} + e \end{aligned} \quad (1)$$

In this equation, Y $(t = 2)$ was one of the achievement- or behavioral-dependent variables measured in the spring of second grade, Y $(t = 0)$ was this same variable measured in kindergarten, WM $(t = 0)$ was the child's working memory, CF $(t = 0)$ was the child's cognitive flexibility, IC $(t = 0)$ was the child's inhibitory control, with each of these EF measured in kindergarten. The equation's controls included all of the other achievement and behavioral variables measured in kindergarten, a measure of the student's oral vocabulary knowledge in kindergarten, as well as sociodemographics, IEP, and age at testing in second grade. Finally, *e* was a random error term. We also tested for interactions between the three EF measured in kindergarten and family SES. This was done by adding the product of SES and each of the kindergarten EF measures to Equation (1).

Results

Table 2 displays a correlation matrix of the study's variables. The achievement measures strongly correlated with each other concurrently at kindergarten and second grade as well as predictively from kindergarten to second grade, with these correlations ranging from .50 to .73. By contrast, the EF variables are only modestly correlated, with coefficients ranging from .17 to .30. These modest correlations are consistent with the notion that these variables represent distinct types of EF.

Table 3 displays standardized coefficient estimates from a series of OLS regressions models predicting children's reading, mathematics, and science achievement, as well as their externalizing and internalizing problem behaviors in second grade. The kindergarten lagged dependent variables consistently predicted children's second-grade academic achievement and classroom behavior. This is the case for both the domain-specific and domain-general dependent variables. For example, second-grade mathematics achievement was predicted not only by prior mathematics achievement (ES = .42, p < .001) but also by prior reading and science achievement (ES = .06 and .09, both p < .001, respectively). Children's vocabulary size in kindergarten also predicted their reading, mathematics, and science achievement in second grade. Additional predictors of second-grade children's academic achievement and classroom problem behaviors included their family SES, the use of a language other than English in the home, being older, and having a disability requiring special education services.

Statistically controlling for both domain-specific and domain-general dependent variables, sociodemographic characteristics, and additional confounds (e.g., simultaneously controlling for working memory when estimating inhibitory control's predictive relation with mathematics achievement), kindergarten children's EF repeatedly predicted their academic achievement and classroom behavior in second grade. These predictive relations were the most domain-general for inhibitory control. Kindergarten children's inhibitory control uniquely predicted their second-grade reading (ES = .09, p < .001), mathematics (ES = .10, p < .001), and science achievement (ES = .06, p < .001). Inhibitory control also negatively predicted the frequency of externalizing and internalizing problem behaviors (ES = −.15 and −.11, p < .001).

Other types of EF displayed relatively more domain-specific relations with children's academic achievement and behavior. Despite extensive statistical control including for inhibitory control, working memory predicted children's second-grade reading, mathematics, and science achievement (ES = .05, p < 001, .06, p < .001, and .10, p < .001, respectively), but was not significantly related to their externalizing or internalizing problem behaviors. Cognitive flexibility also had a positive and significant relation with each of the achievement variables (ES = .10, p < .001, .13, p < .001, and .08, p < .001, respectively) but very small relations with externalizing and internalizing problem behaviors (ES = −.01, p > .05 and −.03, p < .01, respectively).

We also tested for interactions between each of the specific EF types and family SES quintiles. This was done by adding interaction terms to the equations whose estimates are shown in Table 3. Table 4 displays these results, showing only the coefficients for the interaction terms in these equations and using the highest SES quintile as the reference group. The vast majority of the interactions were not statistically significant at conventional levels. However, significant positive interactions were evident between working memory and the lowest versus highest SES quintiles. These occurred for each of the three indicators of academic achievement, suggesting that increasing working memory might be particularly important for children from the lowest SES families.

Discussion

Each of the study's three specific types of EF significantly predicted aspects of children's school functioning in second grade. Inhibitory control was a consistent and domain-general predictor of both academic achievement and classroom behavior. Specifically, greater inhibitory control in kindergarten predicted greater reading, mathematics, and science achievement, as well as fewer externalizing and internalizing problem behaviors in second grade. Inhibitory control's predictive relations with externalizing and internalizing problem behaviors were particularly strong. Working memory and

Table 2
Correlation Matrix of Study's Variables (N = *8,920*)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Reading achievement, spring second grade	1																					
Mathematics achievement, spring second grade	.73	1																				
Science achievement, spring second grade	.69	.71	1																			
Externalizing problem behaviors, spring second grade	−.19	−.17	−.12	1																		
Internalizing problem behaviors, spring second grade	−.20	−.20	−.14	.33	1																	
Working memory, spring kindergarten	.32	.34	.36	−.08	−.08	1																
Cognitive flexibility, spring kindergarten	.53	.56	.50	−.14	−.16	.30	1															
Inhibitory control, spring kindergarten	.34	.32	.25	−.49	−.23	.17	.26	1														
Black	−.12	−.22	−.18	.15	.04	−.11	−.13	−.10	1													
Hispanic	−.20	−.20	−.27	−.04	−.01	−.11	−.19	−.02	−.19	1												
Other race/ethnicity	.08	.11	.07	−.07	−.05	.03	.07	.04	−.13	−.21	1											
Female	.11	−.07	−.05	−.22	−.05	.05	.05	.24	.00	.00	.03	1										
SES, kindergarten	.36	.35	.37	−.11	−.09	.17	.28	.13	−.14	−.32	.10	.01	1									
Child uses non-English at home, spring kindergarten	−.17	−.12	−.25	−.08	−.05	−.11	−.16	.02	−.12	.49	.14	.01	−.28	1								
IEP, spring second grade	−.32	−.29	−.23	.13	.15	−.14	−.22	−.21	.02	.01	−.03	−.11	−.07	−.04	1							
Age (in months), spring second grade	.06	.08	.11	.02	.02	.05	.10	.06	−.01	−.08	−.05	−.08	.00	−.09	.08	1						
Reading achievement, spring kindergarten	.67	.57	.54	−.15	−.17	.27	.52	.30	−.09	−.17	.10	.06	.31	−.14	−.21	.12	1					
Mathematics achievement, spring kindergarten	.64	.72	.61	−.15	−.20	.34	.61	.30	−.16	−.20	.09	−.02	.34	−.16	−.21	.19	.72	1				
Science achievement, spring kindergarten	.50	.50	.60	−.06	−.10	.26	.42	.18	−.15	−.30	.00	−.02	.36	−.32	−.13	.16	.46	.55	1			
Externalizing problem behaviors, spring kindergarten	−.19	−.18	−.14	.56	.19	−.10	−.15	−.70	.12	.00	−.05	−.19	−.10	−.05	.12	.00	−.16	−.16	−.09	1		
Internalizing problem behaviors, spring kindergarten	−.16	−.16	−.12	.11	.26	−.08	−.12	−.24	.03	.03	−.04	−.03	−.09	−.02	.10	.00	−.14	−.17	−.10	.28	1	
Vocabulary score, spring kindergarten	.32	.29	.43	.00	−.04	.19	.26	.10	.04	−.36	.00	.02	.25	−.45	−.10	.06	.25	.24	.30	−.03	−.07	1

Note. IEP = individualized educational program; SES = socioeconomic status.

Table 3
Panel Regression Model Estimates (OLS) of Second-Grade Children's Academic Achievement and Classroom Behaviors (N = *8,920)*

	Reading achievement, spring second grade	Mathematics achievement, spring second grade	Science achievement, spring second grade	Externalizing problem behaviors, spring second grade	Internalizing problem behaviors, spring second grade
Intercept	−0.42***	−0.30**	−1.04***	−0.01	0.02
Working memory, spring kindergarten	0.05***	0.06***	0.10***	0.01	0.01
Cognitive flexibility, spring kindergarten	0.10***	0.13***	0.08***	−0.01	−0.03**
Inhibitory control, spring kindergarten	0.09***	0.10***	0.06***	−0.15***	−0.11***
Black	−0.01	−0.29***	−0.26***	0.17***	−0.10*
Hispanic	0.01	−0.09**	−0.08**	−0.10**	−0.11**
Other race/ethnicity	0.01	0.03	0.01	−0.05	−0.03
Female	0.10***	−0.22***	−0.14***	−0.21***	−0.01
Lowest SES quintile, kindergarten	−0.34***	−0.23***	−0.22***	0.17**	0.11*
Second lowest SES quintile, kindergarten	−0.19***	−0.12***	−0.14***	0.19***	0.11*
Middle SES quintile, kindergarten	−0.11***	−0.09***	−0.07**	0.11***	0.08*
Second highest SES quintile, kindergarten	−0.07**	−0.08**	−0.06*	0.07**	−0.01
Child uses non-English at home, spring kindergarten	0.06	0.16***	0.05	−0.11***	−0.16***
IEP, spring second grade	−0.43***	−0.36***	−0.23***	0.13**	0.25***
Age (in months), spring second grade	−0.03**	−0.04***	−0.01	0.02	0.04*
Reading achievement, spring kindergarten	0.34***	0.06***	0.10***	−0.01	−0.02
Mathematics achievement, spring kindergarten	0.16***	0.42***	0.18***	−0.02	−0.09***
Science achievement, spring kindergarten	0.11***	0.09***	0.27***	0.02	0.003
Externalizing problem behaviors, spring kindergarten	0.03*	0.03*	0.02	0.42***	0.02
Internalizing problem behaviors, spring kindergarten	−0.02*	−0.01	0.01	−0.06***	0.19***
Vocabulary score 12–15	0.32**	0.38***	0.66***	−0.01	−0.01
Vocabulary score 16–19	0.52***	0.52***	1.16***	0.004	0.01
Vocabulary score 20	0.56***	0.60***	1.36***	0.03	−0.05
R^2	.59	.60	.57	.35	.12

Note. Continuous variables standardized. Sampling weight and robust (clustered by kindergarten school) standard errors used. White and Asian children as reference group. IEP = individualized educational program; OLS = ordinary least squares; SES = socioeconomic status.
*$p < .05$. **$p < .01$. ***$p < .001$.

cognitive flexibility were predictive of children's reading, mathematics, and science achievement, but had at most weak relations with their classroom behavior. These predictive relations were evident despite statistical control for many factors that themselves predicted children's later academic achievement and classroom behavior.

Limitations

Our study has several limitations. Unambiguous causal inferences are not possible because of the possible existence of unmeasured variables correlated with both kindergarten EF and the second-grade outcome variables. However, our analyses of

Table 4
Executive Functioning × SES Interaction Estimates for Models in Table 3, OLS Regression Models of Second-Grade Children's Academic Achievement and Classroom Behaviors (N = *8,920)*

	Reading achievement, spring second grade	Mathematics achievement, spring second grade	Science achievement, spring second grade	Externalizing problem behaviors, spring second grade	Internalizing problem behaviors, spring second grade
CF × SES1	−.03	.02	.05	.04	−.07*
CF × SES2	−.02	.04	.08*	.002	−.05
CF × SES3	−.08**	.005	−.01	.06	−.05
CF × SES4	−.05	.02	.02	.03	−.05
WM × SES1	.08**	.11***	.15***	.04	.03
WM × SES2	.01	.08*	.06	.03	.002
WM × SES3	.04	.05	.06*	.05	.02
WM × SES4	.01	.02	.05	.05	−.04
IC × SES1	.04	.09*	.005	.07	−.01
IC × SES2	.01	.02	.02	.06	−.01
IC × SES3	−.04	.001	−.03	.04	−.05
IC × SES4	−.02	.01	−.04	−.04	−.01

Note. Socioeconomic status (SES) is divided into quintiles, with the highest quintile serving as the reference group; CF = cognitive flexibility; WM = working memory; IC = inhibitory control; OLS = ordinary least squares.
$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

the ECLS-K: 2011 data help establish that measures of kindergarten children's EF predict their achievement and behavior several years later even after accounting for many strong confounds (e.g., prior achievement and behavior, oral language, family SES). Thus, and similar to other studies using alternative but analogous analyses of correlational data using statistical controls, our study's findings provide only suggestive evidence of causality (Fuhs et al., 2014; McClelland et al., 2014; Schmitt et al., 2017; Willoughby et al., 2012). Although our ordinary least squares regression models should have allowed for rigorously derived point estimates, other types of findings might have emerged using other types of designs and analytical methods.

We also were unable to estimate the predictive relations with other types of EF (e.g., initiation, emotional control) not directly assessed in the ECLS-K: 2011, although these were likely correlated with measures of the children's academic achievement and classroom behavior during kindergarten. Unlike the ECLS-K: 2011's measures of organizational EF (i.e., working memory and cognitive flexibility), which were directly assessed, the measure of regulatory EF (i.e., inhibitory control) was indirectly assessed through teacher ratings. Teacher ratings are considered the preferred method for assessing inhibitory control, particularly when examining its relations with young children's academic achievement (Allan et al., 2014). Teacher ratings of inhibitory control are also not significantly less predictive of achievement than direct behavioral observational measures (Allan et al., 2014). Our EF estimates may have differed if we had been able to examine children's achievement and behavior throughout the upper elementary or middle school grades. For example, working memory's domain-general relation with academic achievement may begin to fade by middle school (Stipek & Valentino, 2015), possibly because its contributions become more limited relative to the growing importance of domain-specific knowledge as well as peer-based feelings of academic competence.

Theoretical and Practical Contributions

Whether and to what extent children's EF constitute promising targets of early interventions for young children at risk has been unclear, particularly because of recently identified methodological limitations in the extant knowledge base (Clements et al., 2016) including the lack of statistical control for important confounds in the available correlational studies (Jacob & Parkinson, 2015; Willoughby et al., 2012). By addressing identified limitations in this work, our study helps provide new knowledge regarding the potential of EF as targets of early interventions, including for children who may be at risk for academic or behavioral difficulties during the primary grades. Our analyses suggest that EF—particularly inhibitory control—constitute promising targets of early interventions for children at risk.

Although EF has been shown to predict multiple indicators of children's achievement and behavior (e.g., Fitzpatrick & Pagani, 2012; Nayfeld et al., 2013), the relative contribution of specific types of EF has previously been unclear. This is because EF have sometimes been analyzed as a general construct (Nayfeld et al., 2013), or only one or two specific types of EF have been included in the analyses (e.g., Fitzpatrick & Pagani, 2012), or because lagged dependent variables have not always been statistically controlled (e.g., Becker, Miao, Duncan, & McClelland, 2014). The extent to which children's behavior explains initially observed associations between children's EF and their achievement has also been unclear (Berry, 2012; Garon et al., 2008). Our analyses of a nationally representative and longitudinal data set and the greater statistical power afforded by its very large sample size help establish that kindergarten children's EF predict their academic achievement and behavior even when independently assessed several years later, with these estimates generalizable to the population of U.S. kindergarten children.

Among the three specific types of EF evaluated here, inhibitory control was the most consistently predictive of children's academic achievement and behavior. Inhibitory control may have a relatively more consistent domain-general relation with early achievement and behavior because, unlike working memory or other specific EF, it may be more directly involved in school-aged children's ability to disregard irrelevant information as well as better attend to classroom instruction and academic subject matter (Cain, 2006; Laski & Dulaney, 2015), assist in the downregulation of disruptive, inattentive, or withdrawal impulses (Berry, 2012), and facilitate general reasoning processes (Richard & Burchinal, 2013).

That working memory and cognitive flexibility were, in general, related to the academic but not behavioral domains may be due to these EF skills being specifically related to helping children retain and access stored information and shift attention across multiple aspects of learning tasks (e.g., incorporating new information about a character or story plot, using addition, subtraction, and multiplication strategies to complete a multistep word problem). This should result in greater problem solving, hypothesis generation, and adaptive rule use (Cartwright et al., 2017; Nayfeld et al., 2013; Yeniad et al., 2013), but may not be as helpful as inhibitory control to facilitating children's ability to sustain focus on academic material while downregulating initial behavioral impulses that might otherwise interfere with a classroom's activities.

From a practical standpoint, our study's effect size estimates for children's EF were relatively small in magnitude. For example, the ES relating the three EF measures to the three achievement measures varied from .05 to .13 of a standard deviation. These are small in the context of generally accepted conventions for interpreting ES yet are in a similar range or are somewhat above estimates reported in correlational studies of other factors considered malleable through school-based interventions (e.g., classroom instructional practices, teacher quality, school climate, and degree of racial integration). For example, the estimated ES of differing classroom instructional practices on primary-grade children's academic achievement are about .03 to .04 of a standard deviation (e.g., Morgan, Farkas, & Maczuga, 2015). We therefore interpret the predicted EF effect size magnitudes as nontrivial, particularly when considered within the limited set of factors known to be malleable through school-based interventions. Our analyses suggest that increasing at-risk children's inhibitory control capacities may have particularly good "bang for the buck" potential because doing so might be expected to lead to gains in distinct but mutually important aspects of children's development, including multiple aspects of achievement as well as of behavior, over and above what might be expected by intervening only upon achievement or behavior.

Collectively, our findings are consistent with prior theoretical and empirical work indicating that EF is related to children's academic and behavioral functioning during elementary school (Cantin et al., 2016; Garon et al., 2008). This suggest that kindergarten children at risk for academic or behavioral difficulties during this time might be helped by early interventions that (a) directly target their EF or (b) reduce the EF demands of classroom tasks, possibly through strategies that lead to better management of the information being presented (Stipek & Valentino, 2015). Some studies have already evaluated whether interventions designed to train children's EF lead to academic or behavioral gains, with these studies reporting positive impacts including on academic measures in samples of children with or at risk for disabilities (Blair & Raver, 2014; Neville et al., 2013; Peijnenborgh, Hurks, Aldenkamp, Vies, & Hendriksen, 2016). However, methodological limitations in the available experimental as well as quasi-experimental work have also been identified (Jacob & Parkinson, 2015; Kirk et al., 2015; Rapport et al., 2013; Titz & Karbach, 2014), including use of untreated control groups and very small sample sizes (Melby-lervåg, Redick, & Hulme, 2016). Treatment effects have sometimes only been assessed over relatively short-time periods (e.g., 8 weeks). This has led to ambiguity as to whether targeting children's EF is likely to result in sustained achievement or behavioral gains (Neville et al., 2013; Schmitt, McClelland, Tominey, & Acock, 2015). Yet long-term follow-up assessments of EF training may be necessary to fully discern the hypothesized causal effects. Our multiyear study provides empirical evidence of predictive relations between multiple types of EF in kindergarten and independently assessed academic achievement and classroom behavior in second grade in a nationally representative sample, with these relations not explained by many previously identified confounds (Jacob & Parkinson, 2015). Consequently, the study's findings support the potential of EF, particularly inhibitory control, as an additional intervention target in multicomponent and experimentally evaluated interventions with long-term follow-up assessments designed to help children who are experiencing academic and behavioral difficulties during elementary school.

References

Allan, N. P., Hume, L. E., Allan, D. M., Farrington, A. L., & Lonigan, C. J. (2014). Relations between inhibitory control and the development of academic skills in preschool and kindergarten: A meta-analysis. *Developmental Psychology*, *50*, 2368–2379. https://doi.org/10.1037/a0037493

Alloway, T. P., Gathercole, S. E., Kirkwood, H., & Elliott, J. (2009). The cognitive and behavioral characteristics of children with low working memory. *Child Development*, *80*, 606–621. https://doi.org/10.1111/j.1467-8624.2009.01282.x

Baptista, J., Osório, A., Martins, E. C., Verissimo, M., & Martins, C. (2016). Does social-behavioral adjustment mediate the relation between executive function and academic readiness? *Journal of Applied Developmental Psychology*, *46*, 22–30. https://doi.org/10.1016/j.appdev.2016.05.004

Becker, D. R., Miao, A., Duncan, R., & McClelland, M. M. (2014). Behavioral self-regulation and executive function both predict visuomotor skills and early academic achievement. *Early Childhood Research Quarterly*, *29*, 411–424. https://doi.org/10.1016/j.ecresq.2014.04.014

Berry, D. (2012). Inhibitory control and teacher–child conflict: Reciprocal associations across the elementary-school years. *Journal of Applied Developmental Psychology*, *33*, 66–76. https://doi.org/10.1016/j.appdev.2011.10.002

Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *Learning and Individual Differences*, *21*, 327–336. https://doi.org/10.1016/j.lindif.2011.01.007

Blair, C. (2016). Developmental science and executive function. *Current Directions in Psychological Science*, *25*, 3–7. https://doi.org/10.1177/0963721415622634

Blair, C., & Raver, C. C. (2014). Closing the achievement gap through modification of neurocognitive and neuroendocrine function: Results from a cluster randomized controlled trial of an innovative approach to the education of children in kindergarten. *PLoS ONE*, *9*, e112393. https://doi.org/10.1371/journal.pone.0112393

Blair, C., & Raver, C. C. (2015). School readiness and self-regulation: A developmental psychobiological approach. *Annual Review of Psychology*, *66*, 711–731. https://doi.org/10.1146/annurev-psych-010814-015221

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology*, *33*, 205–228. https://doi.org/10.1080/87565640801982312

Bull, R., & Lee, K. (2014). Executive functioning and mathematics achievement. *Child Development Perspectives*, *8*, 36–41. https://doi.org/10.1111/cdep.12059

Cain, K. (2006). Individual differences in children's memory and reading comprehension: An investigation of semantic and inhibitory deficits. *Memory*, *14*, 553–569. https://doi.org/10.1080/09658210600624481

Cantin, R. H., Gnaedinger, E. K., Gallaway, K. C., Hesson-McInnis, M. S., & Hund, A. M. (2016). Executive functioning predicts reading, mathematics, and theory of mind during the elementary years. *Journal of Experimental Child Psychology*, *146*, 66–78. https://doi.org/10.1016/j.jecp.2016.01.014

Cartwright, K. B., Coppage, E. A., Lane, A. B., Singleton, T., Marshall, T. R., & Bentivegna, C. (2017). Cognitive flexibility deficits in children with specific reading comprehension difficulties. *Contemporary Educational Psychology*, *50*, 33–44. https://doi.org/10.1016/j.cedpsych.2016.01.003

Clements, D. H., Sarama, J., & Germeroth, C. (2016). Learning executive function and early mathematics: Directions of causal relations. *Early Childhood Research Quarterly*, *36*, 79–90. https://doi.org/10.1016/j.ecresq.2015.12.009

Diamond, A. (2012). Activities and programs that improve children's executive functions. *Current Directions in Psychological Science*, *21*, 335–341. https://doi.org/10.1177/0963721412453722

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science*, *333*, 959–964. https://doi.org/10.1126/science.1204529

Duncan, S. E., & De Avila, E. A. (1998). *PreLAS 2000*. Monterey, CA: CTB/McGraw-Hill.

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., . . . Japel, C. (2007). School readiness and later achievement. *Developmental Psychology*, *43*, 1428–1446. https://doi.org/10.1037/0012-1649.43.6.1428; 10.1037/0012-1649.43.6.1428.supp (Supplemental)

Fitzpatrick, C., & Pagani, L. S. (2012). Toddler working memory skills predict kindergarten school readiness. *Intelligence*, *40*, 205–212. https://doi.org/10.1016/j.intell.2011.11.007

Friso-van den Bos, I., van der Ven, S. H. G., Kroesbergen, E. H., & van Luit, J. E. H. (2013). Working memory and mathematics in primary school children: A meta-analysis. *Educational Research Review*, *10*, 29–44. https://doi.org/10.1016/j.edurev.2013.05.003

Fuhs, M. W., Nesbitt, K. T., Farran, D. C., & Dong, N. (2014). Longitudinal associations between executive functioning and academic skills across content areas. *Developmental Psychology*, *50*, 1698–1709. https://doi.org/10.1037/a0036633

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, *134*, 31–60. https://doi.org/10.1037/0033-2909.134.1.31

Gathercole, S. E., Alloway, T. P., Kirkwood, H. J., Elliott, J. G., Holmes, J., & Hilton, K. A. (2008). Attentional and executive function behaviours in children with poor working memory. *Learning and Individual Differences*, *18*, 214–223. https://doi.org/10.1016/j.lindif.2007.10.003

Geary, D. C., Hoard, M. K., Nugent, L., & Bailey, D. H. (2012). Mathematical cognition deficits in children with learning disabilities and persistent low achievement: A five-year prospective study. *Journal of Educational Psychology*, *104*, 206–223. https://doi.org/10.1037/a0025398

Gresham, F. M., & Elliott, S. N. (1990). *Social skills rating system*. Minneapolis, MN: NCS Pearson.

Gropen, J., Clark-Chiarelli, N., Hoisington, C., & Ehrlich, S. B. (2011). The importance of executive function in early science education. *Child Development Perspectives*, *5*, 298–304. https://doi.org/10.1111/j.1750-8606.2011.00201.x

Holmes, J., Gathercole, S. E., & Dunning, D. L. (2009). Fast-track report adaptive training leads to sustained enhancement of poor working memory in children. *Developmental Science*, *12*, 1–7. https://doi.org/10.1111/j.1467-7687.2009.00848.x

Jacob, R., & Parkinson, J. (2015). The potential for school-based interventions that target executive function to improve academic achievement: A review. *Review of Educational Research*, *85*, 512–552. https://doi.org/10.3102/0034654314561338

Jarrold, C., & Towse, J. N. (2006). Individual differences in working memory. *Neuroscience*, *139*, 39–50. https://doi.org/10.1016/j.neuroscience.2005.07.002

Kirk, H. E., Gray, K., Riby, D. M., & Cornish, K. M. (2015). Cognitive training as a resolution for early executive function difficulties in children with intellectual disabilities. *Research in Developmental Disabilities*, *38*, 145–160. https://doi.org/10.1016/j.ridd.2014.12.026

Laski, E. V., & Dulaney, A. (2015). When prior knowledge interferes, inhibitory control matters for learning: The case of numerical magnitude representations. *Journal of Educational Psychology*, *107*, 1035–1050. https://doi.org/10.1037/edu0000034

Li-Grining, C. P., Votruba-Drzal, E., Maldonado-Carreño, C., & Haas, K. (2010). Children's early approaches to learning and academic trajectories through fifth grade. *Developmental Psychology*, *46*, 1062–1077. https://doi.org/10.1037/a0020066

McClelland, M. M., Cameron, C. E., Duncan, R., Bowles, R. P., Acock, A. C., Miao, A., & Pratt, M. E. (2014). Predictors of early growth in academic achievement: The head-toes-knees-shoulders task. *Frontiers in Psychology*, *5*, 1–14. https://doi.org/10.3389/fpsyg.2014.00599

Melby-lervåg, M., & Hulme, C. (2013). Is working memory training effective? *A Meta-Analytic Review*, *49*, 270–291. https://doi.org/10.1037/a0028228

Melby-lervåg, M., Redick, T. S., & Hulme, C. (2016). Working memory training does not improve performance on measures of intelligence or other measures of "far transfer": Evidence from a meta-analytic review. *Perspectives on Psychological Science*, *11*, 512–534. https://doi.org/10.1177/1745691616635612

Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., . . . Caspi, A. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences of the United States of America*, *108*, 2693–2698. https://doi.org/10.1073/pnas.1010076108

Monette, S., Bigras, M., & Lafrenière, M.-A. (2015). Structure of executive functions in typically developing kindergarteners. *Journal of Experimental Child Psychology*, *140*, 120–139. https://doi.org/10.1016/j.jecp.2015.07.005

Morgan, P. L., Farkas, G., Hillemeier, M. M., & Maczuga, S. (2016). Science achievement gaps begin very early, persist, and are largely explained by modifiable factors. *Educational Researcher*, *45*, 18–35. https://doi.org/10.3102/0013189X16633182

Morgan, P. L., Farkas, G., & Maczuga, S. (2015). Which instructional practices most help first-grade students with and without mathematics difficulties? *Educational Evaluation and Policy Analysis*, *37*, 184–205. https://doi.org/10.3102/0162373714536608

Morgan, P. L., Farkas, G., & Wu, Q. (2011). Kindergarten children's growth trajectories in reading and mathematics: Who falls increasingly behind? *Journal of Learning Disabilities*, *44*, 472–488. https://doi.org/10.1177/0022219411414010

Morgan, P. L., Li, H., Farkas, G., Cook, M., Pun, W. H., & Hillemeier, M. M. (2016). Executive functioning deficits increase kindergarten children's risk for reading and mathematics difficulties in first grade. *Contemporary Educational Psychology*, *50*, 23–32. https://doi.org/10.1016/j.cedpsych.2016.01.004

Murname, R. J., & Willett, J. B. (2011). *Methods matter: Improving causal inference in educational and social science research*. New York, NY: Oxford University.

Nayfeld, I., Fuccillo, J., & Greenfield, D. B. (2013). Executive functions in early learning: Extending the relationship between executive functions and school readiness to science. *Learning and Individual Differences*, *26*, 81–88. https://doi.org/10.1016/j.lindif.2013.04.011

Neville, H. J., Stevens, C., Pakulak, E., Bell, T. A., Fanning, J., Klein, S., & Isbell, E. (2013). Family-based training program improves brain function, cognition, and behavior in lower socioeconomic status preschoolers. *Proceedings of the National Academy of Sciences of the United States of America*, *110*, 12138–12143. https://doi.org/10.1073/pnas.1304437110

Nutley, S. B., & Soderqvist, S. (2017). How is working memory training likely to influence academic performance? Current evident and methodological considerations. *Fronters in Psychology*, *8*, 1–12.

Peijnenborgh, J. C., Hurks, P. M., Aldenkamp, A. P., Vies, J. S., & Hendriksen, J. G. (2016). Efficacy of working memory training in children and adolescents with learning disabilities: A review study and meta-analysis. *Neuropsychological Rehabilitation*, *26*, 645–672. https://doi.org/10.1080/09602011.2015.1026356

Phillips, N. L., Mandalis, A., Benson, S., Parry, L., Epps, A., Morrow, A., & Lah, S. (2016). Computerized working memory training for children with moderate to severe traumatic brain injury: A double-blind, randomized, placebo-controlled trial. *Journal of Neurotrauma*, *33*, 2097–2104. https://doi.org/10.1089/neu.2015.4358

Putnam, S. P., & Rothbart, M. K. (2006). Development of short and very short forms of the Children's Behavior Questionnaire. *Journal of Personality Assessment*, *87*, 102–112. https://doi.org/10.1207/s15327752jpa8701_09

Rainelli, S., Bulotsky-Shearer, R. J., Fernandez, V. A., Greenfield, D. B., & López, M. (2017). Validity of the first two subtests of the preschool language assessment scale as a language screener for Spanish-speaking preschool children. *Early Childhood Research Quarterly*, *38*, 10–22. https://doi.org/10.1016/j.ecresq.2016.08.001

Rapport, M. D., Orban, S. A., Kofler, M. J., & Friedman, L. M. (2013). Do programs designed to train working memory, other executive functions, and attention benefit children with ADHD? A meta-analytic review of cognitive, academic, and behavioral outcomes. *Clinical Psychology Review*, *33*, 1237–1252. https://doi.org/10.1016/j.cpr.2013.08.005

Richard, L. E., & Burchinal, M. R. (2013). Early executive function predicts reasoning development. *Psychological Science*, *24*, 87–92. https://doi.org/10.1177/0956797612450883

Ropovik, I. (2014). Do executive functions predict the ability to learn problem-solving principles? *Intelligence*, *44*, 64–74. https://doi.org/10.1016/j.intell.2014.03.002

Schmitt, S. A., Geldhof, G. J., Purpura, D. J., Duncan, R., & Mcclelland, M. M. (2017). Examining the relations between executive function, math, and literacy during the transition to kindergarten: A multi-analytic approach. *Journal of Educational Psychology*. https://doi.org/10.1037/edu0000193

Schmitt, S. A., McClelland, M. M., Tominey, S. L., & Acock, A. C. (2015). Strengthening school readiness for Head Start children: Evaluation of a self-regulation intervention. *Early Childhood Research Quarterly*, *30*, 20–31. https://doi.org/10.1016/j.ecresq.2014.08.001

Schrank, F. A. (2011). Woodcock–Johnson III tests of cognitive abilities. In A. S. Davis (Ed.), *Handbook of pediatric neuropsychology* (pp. 415–434). New York, NY: Springer.

Seigneuric, A., & Ehrlich, M. F. (2005). Contribution of working memory capacity to children's reading comprehension: A longitudinal investigation. *Reading and Writing: An Interdisciplinary Journal*, *18*, 617–656. http://dx.doi.org/10.1007/s11145-005-2038-0

Stipek, D., & Valentino, R. A. (2015). Early childhood memory and attention as predictors of academic growth trajectories. *Journal of Educational Psychology*, *107*, 771–788. https://doi.org/10.1037/edu0000004

Titz, C., & Karbach, J. (2014). Working memory and executive functions: Effects of training on academic achievement. *Psychological Research*, *78*, 852–868. https://doi.org/10.1007/s00426-013-0537-1

Toll, S. W. M., Van der Ven, S. H. G., Kroesbergen, E. H., & Van Luit, J. E. H. (2011). Executive functions as predictors of math learning disabilities. *Journal of Learning Disabilities*, *44*, 521–532. https://doi.org/10.1177/0022219410387302

Tourangeau, K., Nord, C., Lê, T., Sorongon, A. G., Hagedorn, M. C., Daly, P., & Najarian, M. (2015). *Early Childhood Longitudinal Study, Kindergarten class of 2010–11 (ECLS-K: 2011). User's manual for the ECLS-K: 2011 kindergarten data file and electronic codebook, public version. NCES 2015-074*. Washington, DC: National Center for Education Statistics.

Viterbori, P., Usai, M. C., Traverso, L., & De Franchis, V. (2015). How preschool executive functioning predicts several aspects of math achievement in Grades 1 and 3: A longitudinal study. *Journal of Experimental Child Psychology*, *140*, 38–55. https://doi.org/10.1016/j.jecp.2015.06.014

Vitiello, V. E., Greenfield, D. B., Munis, P., & George, J. (2011). Cognitive flexibility, approaches to learning, and academic school readiness in Head Start preschool children. *Early Education & Development*, *22*, 388–410. https://doi.org/10.1080/10409289.2011.538366

Willoughby, M. T., Kupersmidt, J. B., & Voegler-Lee, M. E. (2012). Is preschool executive function causally related to academic achievement? *Child Neuropsychology*, *18*, 79–91. https://doi.org/10.1080/09297049.2011.578572

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

Yeniad, N., Malda, M., Mesman, J., van IJzendoorn, M. H., Emmen, R. A. G., & Prevoo, M. J. L. (2014). Cognitive flexibility children across the transition to school: A longitudinal study. *Cognitive Development*, *31*, 35–47. https://doi.org/10.1016/j.cogdev.2014.02.004

Yeniad, N., Malda, M., Mesman, J., van IJzendoorn, M. H., & Pieper, S. (2013). Shifting ability predicts math and reading performance in children: A meta-analytical study. *Learning and Individual Differences*, *23*, 1–9. https://doi.org/10.1016/j.lindif.2012.10.004

Zelazo, P. D., Anderson, J. E., Richler, J., Wallner-Allen, K., Beaumont, J. L., & Weintraub, S. (2013). II. NIH toolbox cognition battery (CB): Measuring executive function and attention. *Monographs of the Society for Research in Child Development*, *78*, 16–33. https://doi.org/10.1111/mono.12032