Title
Executive Functioning Deficits Increase Kindergarten Childrens Risk for Reading and Mathematics Difficulties in First Grade.

Authors
Morgan, Paul
Li, Hui
Farkas, George
et al.

Publication Date
2017-07-01

DOI
10.1016/j.cedpsych.2016.01.004

Peer reviewed

HHS Public Access
Author manuscript
Contemp Educ Psychol. Author manuscript; available in PMC 2018 July 01.

Published in final edited form as:
Contemp Educ Psychol. 2017 July ; 50: 23–32. doi:10.1016/j.cedpsych.2016.01.004.

Executive Functioning Deficits Increase Kindergarten Children's Risk for Reading and Mathematics Difficulties in First Grade

Paul L. Morgan, Ph.D.,
The Pennsylvania State University

Hui Li, Ph.D.,
The Pennsylvania State University

George Farkas, Ph.D.,
University of California, Irvine

Michael Cook, M.S.,
The Pennsylvania State University

Wik Hung Pun, M.S., and
The Pennsylvania State University

Marianne M. Hillemeier, Ph.D., M.P.H.
The Pennsylvania State University

Abstract

Whether executive functioning deficits result in children experiencing learning difficulties is presently unclear. Yet evidence for these hypothesized causal relations has many implications for early intervention design and delivery. We used a multi-year panel design, multiple criterion and predictor variable measures, extensive statistical control for potential confounds including autoregressive prior histories of both reading and mathematics difficulties, and additional epidemiological methods to preliminarily examine these hypothesized relations. Results from multivariate logistic regression analyses of a nationally representative and longitudinal sample of 18,080 children (i.e., the Early Childhood Longitudinal Study-Kindergarten Cohort of 2011, or ECLS-K: 2011) indicated that working memory and, separately, cognitive flexibility deficits uniquely increased kindergarten children's risk of experiencing reading as well as mathematics difficulties in first grade. The risks associated with working memory deficits were particularly strong. Experimentally-evaluated, multi-component interventions designed to help young children with reading or mathematics difficulties may also need to remediate early deficits in executive function, particularly in working memory.

Please address correspondence to: Paul L. Morgan, Department of Educational Policy Studies, 311 Rackley Building, the Pennsylvania State University, University Park, PA, 16802, (814) 863-0619 (office) paulmorgan@psu.edu.

Keywords

Executive functioning; working memory; cognitive flexibility; learning difficulties; longitudinal

Young children experiencing learning difficulties in reading or mathematics are at risk of having far fewer educational and societal opportunities as they age (Geary, 2011; Juel, 1988; Morgan, Farkas, & Wu, 2011; Watts, Duncan, Siegler, & Davis-Kean, 2014). For example, kindergarten children with lower levels of reading or mathematics achievement are less likely as adults to attend college, be employed, own their own homes, have 401(k) savings, be married, or live in higher-income neighborhoods (Chetty et al., 2011; Parson & Bynner, 1997; Rivera-Batiz, 1992). Learning difficulties in reading or mathematics also increase children's risk for feelings of inferiority, isolation, and generalized socio-emotional maladjustment (Chapman, 1988; Lin et al., 2014; Morgan, Farkas, Tufis, & Sperling, 2008). These relations are evident as early as the elementary grades. For example, third grade children who are poor readers are more likely to subsequently report feelings of anger, sadness, and peer rejection (Morgan, Farkas, & Maczuga, 2012). Learning difficulties are highly stable (e.g., Juel, 1988; Morgan et al., 2011), even as early as kindergarten (Morgan, Farkas, & Wu, 2009a). Collectively, these findings have led to repeated calls for interventions to be delivered early in children's school careers. Early interventions may be necessary in order to best help those children with or at risk of experiencing reading or mathematics difficulties (e.g., Blachman et al., 2014; Clark, Pritchard, & Woodward, 2010; Partanen & Siegel, 2014).

Executive Functioning Deficits as Possibly Contributing to Children's Learning Difficulties

Executive functioning deficits have often been identified as potential targets of early intervention efforts designed to help young children experiencing reading or mathematics difficulties (e.g., Bull, Espy, & Wiebe, 2008; Bull & Scerif, 2001; Pham & Hasson, 2014; Pickering & Gathercole, 2004; Swanson & Saez, 2003; Swanson, Zheng, & Jerman, 2009; Toll, van der Ven, Kroesbergen, & van Luit, 2012; Van der Van, Kroesbergen, Boom, & Leseman, 2012). Executive functions are mental processes that allow individuals to regulate their behaviors in order to better meet goals, particularly those that may be more cognitively taxing (e.g., classroom tasks) because they are not routine (Banich, 2009). Schoolchildren with well-developed executive functions should be able to better plan, maintain attention, remember and then independently apply teacher-provided instruction, and alternate their attention between multiple classroom tasks. Working memory and cognitive flexibility are two types of executive functions (Banich, 2009; Center on the Developing Child, 2011; Fisk & Sharp, 2004; Miyake, Friedman, Emerson, Witzki, Howerter, & Wagner, 2000; Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003; Learner & Lonigan, 2014). Deficits in these executive functions have been hypothesized to result in learning difficulties because they interfere with young children's success in classrooms, including understanding instruction as well as managing and selectively ignoring simultaneous demands on their attention while completing assigned work (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Gathercole, Durling, Evans, Jeffcock, & Stone, 2008). Direct observation finds that children with executive functioning deficits more frequently fail to complete multi-step instructions by their teachers and to finish complex tasks (Gathercole, Lamont, & Alloway, 2006). These deficits are also thought to interfere with children's mathematics as well as reading achievement (Swanson & Beebe-Frankenberger, 2004). For example, working memory and cognitive flexibility deficits have been reported to constrain children's counting abilities, fact retrieval (Geary, Hoard, Nugent, & Bailey, 2012; Noel, 2009), and mathematics problem solving (Andersson, 2008; Swanson, Jerman, & Zheng, 2008). This may occur due to the children struggling with (a) storing and then manipulating symbolic information and (b) shifting between several strategies or following multistep solution procedures (Toll et al., 2011; Van der Sluis et al., 2007). Working memory or cognitive flexibility deficits also have been reported to interfere with children's reading fluency and comprehension monitoring (Cain, Oakhill, & Bryant, 2004; Sesma, Mahone, Levine, Eason, & Cutting, 2009). This may occur as the children struggle to hold and integrate information from their long-term memories while also trying to process and make inferences about assigned texts (Locascio, Mahone, Eason, & Cutting, 2010; Swanson & Beebe-Frankenberger, 2004). Children with learning difficulties are known to be at higher risk of having executive functioning deficits (August & Garfinkel, 1990; Gathercole, Alloway, Willis, & Adams, 2006).

Limited Evidence of a Causal Relation between Executive Functioning Deficits and Learning Difficulties

Yet whether and to what extent executive functioning deficits are causally related to the onset of learning difficulties—and so constitute potential targets of early intervention efforts—is presently unclear. Methodologically, most existing work has relied on cross-sectional designs (Gathercole, 2005) and has not fully accounted for potential confounding factors that may explain any initially observed relations between executive functioning deficits and children's reading or mathematics difficulties (Jacob & Parkinson, 2015).[1] Potential confounds include background characteristics of children (e.g., prior academic achievement, prior behavioral functioning, gender, age, race/ethnicity) and their families (e.g., household income and other indictors of socioeconomic status) (Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013; Jacob & Parkinson, 2015). Children's own prior academic functioning and their family's socioeconomic status (SES) have been identified as particularly strong potential confounds (Jacob & Parkinson, 2015). Additional factors that might be related to children's academic achievement and so should be statistically controlled include participation in programs that are designed to mitigate the early impacts of economic deprivation, as well as childcare attendance (Geoffroy et al., 2010; Jyoti, Frongillo, & Jones, 2005). Due in part to these aforementioned methodological limitations, the existing work has been characterized recently as providing "no compelling evidence" (Jacobs & Parkinson, 2015, p. 30) as to whether children's executive functions are causally related to their academic achievement. Establishing that deficits in executive function (a) temporally precede learning difficulties in reading or mathematics and (b) are uniquely predictive of these difficulties after accounting for strong potential confounds would provide stronger

[1]As reported more fully by Jacob and Parkinson (2015), methodological limitations in the existing experimental studies also make it unclear as to whether executive function training increases children's academic achievement (see, for example, pp. 24-29)

preliminary evidence of the hypothesized causal relations (Finkel, 1995), and so might inform intervention design efforts to help young children with reading or mathematics difficulties. (These intervention design efforts would then be experimentally evaluated to provide unambiguous causal evidence.)

Substantively, few studies have been conducted that included multiple subcomponents of executive function in their analyses (Jacob & Parkinson, 2015). This has resulted in ambiguity as to which of the multiple subcomponents (e.g., working memory, inhibitory control, cognitive flexibility) constitute comparatively more promising targets of interventions designed to prevent or remediate learning difficulties. Theoretically, working memory deficits might constitute especially strong impediments to young children's academic achievement, particularly in mathematics (Toll et al., 2011). This is because many classroom tasks given in the primary grades (e.g., counting, solving single-digit addition and subtraction problems) often require children to store as well as manipulate information. In contrast, other types of executive functioning deficits, including in cognitive flexibility, may not be as important during the primary grades. For example, relatively fewer classroom tasks during these grades require solving multi-step problems, thereby placing fewer demands on children with cognitive flexibility deficits (van der Sluis, de Jong, & van der Leij, 2004). Yet whether working memory or cognitive flexibility deficits should receive greater emphasis in early intervention designs is presently unclear because of the lack of studies that have simultaneously examined the predictive utility of both types of deficits in explaining children's risk for learning difficulties (Jacob & Parkinson, 2015).

Additionally, and although prior studies have examined whether and to what extent executive functions are related generally to children's achievement in reading or mathematics, less clear is whether specific executive functioning deficits are related to learning difficulties in both reading mathematics, particularly after accounting for the strong potential confounds of children's background characteristics (Jacob & Parkinson, 2015). Thus, it remains to be empirically established whether these deficits are more likely to constrain children's mathematics than reading achievement. Relatedly, finding that executive functioning deficits increase children's likelihood of experiencing learning difficulties in both both mathematics and reading would suggest that these deficits may constitute especially important targets of early intervention efforts for at-risk children. Currently, very few of the available studies have analyzed population-based as well as longitudinal samples, thereby limiting both generalizability of the field's knowledge base as well as evidence of unique predictive relations between children's executive functioning deficits and their later risk for academic struggles. For example, Jacob and Parkinson's (2015) synthesis of 67 studies reported an average sample size of 237, with 23 of these studies examining the relation between executive function and academic achievement longitudinally.

Purpose

We examined whether and to what extent executive functioning deficits uniquely predicted kindergarten children's risk of later experiencing reading or mathematics difficulties. To address recently identified methodological and substantive limitations in the existing work, we (a) analyzed a population-based and multi-year longitudinal sample of U.S.

schoolchildren, (b) included measures of two types (i.e. working memory, cognitive flexibility) of executive functioning deficits, (c) examined these hypothesized relations predictively instead of concurrently, and (c) statistically controlled for strong potential confounds, including the autoregressors of prior learning difficulties as well as family SES and children's own prior behavioral functioning. Simultaneously adjusting for autoregressive learning difficulties in both reading and mathematics should result in especially strong statistical control for potential confounds. By examining whether and to what extent executive functioning deficits temporally precede reading and mathematics difficulties and remain uniquely predictive of these difficulties following statistical control for many potential confounds during the primary grades, our study's analyses should help clarify to what extent executive functioning deficits may be potentially causally related to the onset of these difficulties. Examining these relations during the primary grades should help clarify whether executive functioning deficits constitute potential targets of early intervention design efforts for young children with or at risk of experiencing reading or mathematics difficulties.

Method

Database

We analyzed the restricted version of the nationally representative Early Childhood Longitudinal Study, Kindergarten class of 2011 (ECLS-K: 2011) dataset. The ECLS-K: 2011 is maintained by the National Center for Educational Statistics (NCES) of the U.S. Department of Education's Institute of Education Sciences. Analyzed data were collected in the fall of 2010, fall and spring of 2011, and spring of 2012. These dates generally corresponded to children being enrolled in kindergarten and first grade. The entire ECLS-K: 2011, which consisted of around 18,080 children, served as our analytical sample. Table 1 displays the analytical sample's descriptive characteristics, with and without sample weighting.

Criterion Variables

Learning difficulties in reading or mathematics—Field staff from NCES administered untimed, item response theory (IRT)-scaled reading and mathematics assessments that displayed strong psychometric properties (Tourangeau et al., 2015). Specifications for the assessments were based on the 2009 NAEP Reading and 1996 NAEP Mathematics Frameworks. We analyzed scores from the spring of kindergarten and first grade administrations of these assessments. The reading achievement assessments contained items relating to basic skills (print familiarity, letter recognition, beginning and ending sounds, sight vocabulary, and recognizing common words), vocabulary knowledge (including receptive vocabulary and vocabulary in context), and reading comprehension. For both the kindergarten and first grade reading achievement assessments, most items were related to basic reading skills as opposed to vocabulary knowledge and reading comprehension. The mathematics achievement assessments contained items relating to declarative, procedural, and conceptual knowledge. Additional content included: (a) number sense and number properties; (b) basic mathematical operations; (c) measurement; (d) geometry and spatial sense; (e) data analysis, statistics, and probability; and (f) patterns, algebra, and functions. Theta reliabilities for the reading and math assessments were .95 and .94, respectively.

To evaluate whether deficits in working memory or cognitive flexibility uniquely predicted kindergarten children's later risk of experiencing learning difficulties in reading or mathematics, including after statistical control for autoregressive prior histories of reading or mathematics difficulties, children's scores on the reading and mathematics assessments were dummy coded as "1" when the scores were in the bottom 10% of the entire distribution of scores at either first grade or kindergarten assessment. One dummy variable was created for each of the two assessments. Children with scores in the top 90% of the reading and mathematics achievement assessments were the respective reference groups. The use of a 10% cutoff has been used in prior research to identify children experiencing learning difficulties as well as disabilities (Dirks, Spyer, van Lieshout, de Sonneville, 2008; Geary, 2011; Murphy, Mazzocco, Hanich, & Early, 2007; Mazzocco, 2001).

A 10% cut off is also consistent with the estimated prevalence of mathematics and reading disabilities as well as specific language impairment in samples of young children (e.g., Geary, 2011; Landerl & Moll, 2009; Moll; Kunze, Neuhoff, Bruder, & Schulte-Korne, 2014; Shaywitz, Shaywitz, Fletcher, & Escobar, 1990; Tomblin et al., 1997). (As a further robustness check, we also used the alternative cut offs of 15% and 25% to identify children with reading or mathematics difficulties as well as those with executive functioning deficits. We also estimated these relations continuously. Please see the Appendix's Supplemental Tables 1-3 for these results, which were consistent with those reported in the study's main text.)

Predictor Variables

We were especially interested in whether and to what extent executive functioning deficits in working memory or cognitive flexibility by the spring of kindergarten predicted reading or mathematics difficulties by the spring of first grade.

Working memory deficits—Working memory was measured by using the Numbers Reversed subtest of the Woodcock-Johnson III Tests of Cognitive Abilities (Mather & Woodcock, 2001). The Numbers Reversed task has been used extensively in psychological research as part of a Working Memory cluster score (Flanagan, McGrew, & Ortiz, 2000). Floyd et al. (2006) found that working memory scores based largely on the Numbers Reversed scale positively correlated with other measures of working memory. Reliability coefficients for the Numbers Reversed subtest have been consistently found to be above .90 (Mather & Woodcock, 2001). This assessment had children repeat back sets of single-digit numbers in the reverse order that the numbers were presented. For example, if the test administrator presented the numbers "3, 5, 7", a child who said "7, 5, 3" correctly answered the item. A child was given five two-digit sequences. Testing was stopped if the child provided incorrect answers for three consecutive sequences. Otherwise, the child was given five three-digit sequences. The procedure was repeated with progressively longer sequences (to a maximum of eight digits) until three consecutive sequences were answered incorrectly. Item-level data were available for this task, with a total of 30 possible items (five two-digit sequences, five three-digit sequences, four four-digit sequences, four five-digit sequences, four six-digit sequences, four seven-digit sequences, and four-eight digit sequences). Responses were coded as “correct,” “incorrect,” or “not administered.” Scores were recoded into *W* scores as recommended by the measure’s publishers (Mather & Woodcock, 2001). The *W* scale is a standardized scale that has a mean of 500 and a standard deviation of 100. Use of the *W* scale was advantageous in our study because it measured both correct responding and task difficulty, and helped track growth over time (Tourangeau et al., 2015). The *W* scale is an equal-interval scale that allows the child’s ability level and the difficulty of the items to be measured on the same scale (Jaffe, 2009). Consequently, a one-unit change on the scale represents a one-unit change in the child’s ability level, regardless of where in the distribution the child’s particular score resides. A change in the *W* scale represented growth in the trait being measured instead of simply a change in relative rank order.

Cognitive flexibility deficits—Cognitive flexibility was measured using the Dimensional Change Card Sort (DCCS; Zelazo, 2006). The DCCS has been used repeatedly to study executive function in childhood (Benson, Sabbagh, Carlson, & Zelazo, 2013; Carlson, White, & Davis-Unger, 2014; Kloo et al., 2008; Leyva et al., 2015; Obradović, 2010; Schmitt, McClelland, Tominey, & Acock, 2015; Wade et al., 2014; White et al., 2011; Zelazo et al., 2014). The original form of the DCCS was designed for use with three- to five-year-old children. However, the measure has also been used with older samples (e.g., Cutuli et al., 2010; Masten et al., 2012; Obradović, 2010). The DCCS was administered in the spring of both kindergarten and first grade. The task required children to sort 22 different picture cards on the basis of different rules. The cards had a picture of either a red rabbit or a blue boat. Children were asked to sort the 22 cards on the basis of the sorting rule that they were given (either by color or by shape). Each child was 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). If a child performed well enough on the Shape game (i.e., sorts four of six cards correctly), then the child was asked to play the Border game. In the Border game, were sorted on the basis of whether or not they have a black border. The child was asked to sort cards with black borders by color and cards without black borders by shape. Item-level data were available for each of the three games (six variables for each game). The DCCS has very strong test-retest reliabilities, with intra-class correlations generally ranging from .90-.94.

We identified children whose scores on the two executive functioning measures were in the bottom 10% of the distribution as having working memory or cognitive flexibility deficits. Specifically, children whose scores on either measure were in the bottom 10% of the distribution were coded as a “1” indicating a deficit. Those children in the top 90% of the score distribution were coded a “0,” indicating no deficit. Our cut-off of 10% was more conservative than cut-off scores used in earlier work to identify children with executive functioning deficits (Alloway, Gathercole, Kirkwood, & Elliott, 2009). Use of a 10% cut off is also a fairly restrictive criterion to identify children with or at risk for having disabilities (Forness et al., 1998; Morgan, Farkas, Tufis, & Sperling, 2008) including those who may have deficits in executive function (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Murphy, Mazzocco, Hanich, & Early, 2007).

Control Variables

We statistically controlled for additional factors that might themselves be predictive of reading or mathematics difficulties and so, if not included as covariates, might potentially confound any observed predictive relations between these difficulties and executive functioning deficits. In addition to children's prior history of reading or mathematics difficulties, we also controlled for children's prior behavioral functioning, their or their family's socio-demographic characteristics, and their family's participation in governmental assistance or childcare (Friso-van den Bos, 2013; Geoffroy et al., 2010; Jacob & Parkinson, 2015).

Prior behavioral functioning—The ECLS-K: 2011 uses a modified version of the psychometrically validated Social Skills Rating System (SSRS; Gresham & Elliot, 1990) to measure children's behavioral functioning. We used subscale measures of children's behavioral self-regulation and externalizing and internalizing problem behaviors as statistical controls when examining the relation between executive functioning deficits and learning difficulties. Kindergarten teachers rated the children's behavior in the spring. The Approaches to Learning subscale consisted of seven items that examined how often a student displayed behavioral self-regulation (e.g., works independently, easily adapts to changes in routine, persists in completing tasks, pays attention well, follows classroom rules) (e.g., Li-Grining, Votruba-Drzal, Maldonado-Carreno, & Hass, 2010). The Internalizing Problem Behaviors subscale consisted of four items (e.g., is the child lonely, sad, or anxious), while the Externalizing Problem Behaviors subscale consisted of five items (i.e., e.g., argues, fights, acts impulsively, gets angry). For each subscale, teachers rated children's behavior on a four-point scale from "never" to "very often." Higher scores indicated that the behavior occurred more frequently. The internal consistency reliability coefficients for the Approaches to Learning, Internalizing, and Externalizing subscales were .91, .78, and .89, respectively. Continuous scores from the three subscales were used as covariates in the study's analyses. Covariate adjustment for prior behavioral self-regulation should help statistically control for other types of executive functioning including attention and inhibitory control (Fuhs, Farran, & Nesbitt, 2015). Behavioral self-regulation is known to strongly predict young children's academic achievement (e.g., Duncan et al., 2007), including that of children at risk (Lin et al., 2014; Morgan et al., 2008).

Socio-demographic characteristics—Parents identified their child's age (in months), gender, and race or ethnicity in the kindergarten parent interview. The child's race was reported in one of the following categories: White, non-Hispanic; Black, non-Hispanic; Hispanic; Asian; or Other. NCES calculated a household's socioeconomic status (SES) using a composite of variables indicating each parent's or guardian's education level and occupation as well as the parent-report household income. The family's SES was included as a continuous variable in the analysis. We also included as a predictor whether the household was below the federal poverty level.

Use of governmental assistance, childcare—During spring of their child's kindergarten year, parents were asked whether they had received food stamps at least once in the past 12 months. To determine whether Women, Infants, and Children (WIC) assistance had ever been provided to the household, the parental respondent was asked two questions: “Did the household receive WIC assistance while the mother was pregnant,” and “did the child receive WIC assistance as an infant or a toddler?” The respondent was also asked about the childcare arrangements. We included as a variable whether the child regularly attended a center-based child care program. Parents were also asked whether they had received temporary assistance for needy families (TANF) in the last 12 months.

Missing Data

Due to the ECLS-K: 2011’s large sample size and large amount of data collection over a multi-year time frame, there was some missing data between kindergarten and first grade. However, the ECLS-K: 2011 data provided detailed and extensive information on many child, parent, teacher, and school variables including those that missingness was likely conditional upon (e.g., family SES, children’s academic achievement and behavior). We used multiple imputation (MI), a technique that retained the largest possible sample size for the study’s analyses. Use of MI is advantageous because it incorporates uncertainty into the standard errors of imputed values by accounting for variance from the imputed solutions (Acock, 2005; Allison, 2001; Rubin, 1996), and, along with maximum likelihood, provides the best general method for achieving unbiased regression estimates in the presence of missing data. Use of multiple imputation is considered “statistically rigorous” (Rendall, Ghosh-Dastidar, Weden, Baker, & Nazarov, 2013, p. 485). Missingness ranged from 0% to 30% across the study’s predictors. We imputed the missing data five times to create five data sets, which allowed us to estimate five sets of model parameters. We then combined these five sets of estimates into one using standard formulas derived by Rubin (1987).

Data Analyses

We analyzed the data using autoregressive logistic regression models. All analyses were performed with SAS Version 9.3. We standardized all continuous variables in the models to facilitate their regression coefficient interpretation. We used standard alpha levels (i.e., $p < .05$, .01, and .001) for the study’s main analyses. Table 2 displays the results of these analyses in terms of odds ratios. For each population of interest, odds ratios were calculated for the risks of having reading difficulties or, separately, mathematics difficulties in first grade. The odds of an event occurring are the ratio of the probability of it occurring, divided by the probability of it not occurring. An odds ratio is the ratio of these odds for individuals with one score on an independent variable compared to those with a different score on this variable. (When the independent variable is composed of two groups, the odds ratio is the ratio of the odds for each group.) An odds ratio of 1.0 indicates no effect by the predictor variable on the outcome. An odds ratio greater than 1.0 indicates a positive predicted effect, while an odds ratio below 1.0 indicates a negative predicted effect. Table 2’s Model 1 displays the predictive relations between two types of executive functioning deficits and two types of learning difficulties, statistically controlling for autoregressive prior histories of learning difficulties. Model 2 simultaneously adjusts for additional potential confounds, providing extensively covariate-adjusted estimates of the extent to which executive functioning deficits uniquely increased kindergarten children’s risk of experiencing learning difficulties in reading or mathematics by the end of first grade.

We also undertook a dominance analysis (Budescu, 1993) in order to compare the relative magnitudes of the contribution of working memory and cognitive flexibility deficits to learning difficulties. Dominance analysis uses pseudo *R* squared to measure the fit of the model for logistic regressions. It first establishes the baseline pseudo *R* squared with all predictors except those sought to be compared. Then, each of the additional predictors being compared is separately added into this subset model to get the contribution of each additional predictor. The one with larger contribution dominates. The pseudo *R* squared we used in our analysis is Nagelkerke's *R* squared. This analysis gave similar results to that based on comparing the relative magnitudes of the coefficients of each of the executive functioning predictors.

As briefly noted previously, we also conducted a supplementary set of analyses (please see the Appendix's Supplementary Tables). As a robustness check, we used (a) two additional cut points for executive functioning deficits and reading or mathematics difficulties (i.e., lowest 15% and 25%) and (b) continuous instead of dichotomous variables for working memory, cognitive flexibility, and reading or mathematics achievement. We also examined whether children's executive functions and academic achievement co-varied in kindergarten. We did so because establishing whether two variables co-vary is a less stringent but still necessary condition for causality (Finkel, 1995).

Results

Model 1 in Table 2 shows that prior histories of learning difficulties in both reading and mathematics were strongly predictive of both types of difficulties. Further, after controlling these prior learning difficulties, kindergarten children with working memory or cognitive flexibility deficits were at elevated risk for learning difficulties in reading as well as mathematics by the end of first grade. The odds of having reading difficulties in first grade increased by, respectively, 2.66 and 1.35, for kindergarten children with working memory or cognitive flexibility deficits. Similar odds for mathematics difficulties were, respectively, 3.38 and 1.79. The relative magnitude of these coefficients suggests that while both are statistically significant, the effects of working memory deficits were stronger than those of cognitive flexibility deficits for predicting both reading and mathematics difficulties. This relative magnitude of effects was supported by the dominance analysis of Model 1 shown in Table 3. Working memory deficits contributed more strongly than cognitive flexibility deficits to children's later risk for learning difficulties.

The logistic regressions in Model 2 of Table 2 continued to statistically control for the same- and other-domain autoregressors while also including additional potential confounds. Model 2's results indicated that additional factors were also predictive of experiencing learning difficulties in reading or mathematics in first grade. Two of these factors were consistently related to children's risk of learning difficulties in either academic domain—family SES and kindergarten children's own behavioral self-regulation. For example, the odds that kindergarten children with greater behavioral self-regulation (e.g., those 1 *SD* above the *M*) would experience reading or mathematics difficulties as first graders were about 40% lower (1 - .62 or 1 - .61) than for kindergarten children with typical behavioral self-regulation. Gender and race/ethnicity intermittently predicted children's risk for learning difficulties.

Model 2's results indicated that working memory and cognitive flexibility deficits continued to uniquely predict kindergarten children's increased risk for learning difficulties in both reading and mathematics in first grade. This is despite statistical controls for the autoregressors of prior histories of reading and mathematics difficulties, socio-demographics, three types of behavioral functioning including approaches to learning, and additional factors. Specifically, the covariate-adjusted odds that kindergarten children with working memory deficits would experience reading and mathematics difficulties in first grade were 2.17 and 2.87 times larger than for otherwise similar kindergarten children without working memory deficits. Kindergarten children with cognitive flexibility deficits had odds of experiencing reading or mathematics difficulties that were, respectively, 1.27 and 1.71 times those without such deficits, even after statistically controlling for many potential confounds.

Overall, Model 2's results indicated that executive functioning deficits were uniquely predictive of experiencing later learning difficulties. This general relation was evident across two specific types of executive functioning deficits and across two specific types of learning difficulties, as well as following extensive statistical control for many potential confounds including two types of autoregressors. We subsequently tested several additional inter-relations and found that executive functioning deficits (whether in working memory or in cognitive flexibility) were more strongly related to mathematics difficulties than reading difficulties (*p*- value levels of .0023 for reading and .018 for mathematics). Based on the dominance analysis of Model 2 presented in Table 3, children's mathematics or reading difficulties in first grade were more strongly predicted by earlier deficits in working memory than in cognitive flexibility (*p*- value level of .001).

The study's supplemental analyses indicated that these relations between working memory or cognitive functioning deficits and children's learning difficulties were robust to various criterion specifications. When examined continuously instead of dichotomously, and despite extensive statistical control including for the strong confounds of prior reading and mathematics achievement, kindergarten children's working memory and cognitive flexibility continued to uniquely predict their first grade reading and mathematics achievement. Children's executive functions and academic achievement co-varied by the spring of kindergarten.

Discussion

Our results indicated that kindergarten children with working memory and cognitive flexibility deficits were at increased risk of experiencing reading and mathematics difficulties in first grade. These predictive relations were not explained by many potential confounds, including children's prior histories of reading or mathematics difficulties, their own prior behavioral functioning including self-regulation, and their family's SES. These confounding factors were themselves strongly predictive of kindergarten children's risk for learning difficulties.

Limitations

Our study has several limitations. First, the ECLS-K: 2011 dataset does not include a measure of IQ. This also has been identified as a potential confound of a causal relation between executive function and academic achievement (Jacob & Parkinson, 2015). However, prior work has also found that IQ is highly correlated with academic achievement (Rohde & Thompson, 2007). For example, Naglieri and Bornstein's (2003) synthesis indicated that IQ and academic achievement correlated as highly as .74. Our analyses did control for children's prior histories of very low achievement in both reading and mathematics. Second, data from the ECLS-K: 2011 sample were available only to the end of first grade. We were therefore unable to report whether these predictive relations continue to occur or fluctuate as children age. For example, it may be that cognitive flexibility deficits begin to interfere more strongly with children's academic achievement as they continue past the primary grades. Third, the ECLS-K data are non-experimental. Although the ECLS-K: 2011 data allow for hypothesis generation and may also provide preliminary evidence of a potential causal relation, they do not allow for unambiguous causal inferences. Experimental studies, including those that help address those methodological limitations recently identified by Jacob and Parkison (2015), are necessary to conclusively establish that remediating executive functioning deficits results in greater academic achievement. Fourth, the ECLS-K: 2011 data include direct measures of working memory and cognitive flexibility but not direct measures of other specific executive functions. We therefore were unable to examine whether other types of executive functioning deficits (e.g., in attention or inhibitory control) were also uniquely predictive of children's increased risk for learning difficulties. We did include the ECLS-K: 2011's measure of behavioral self-regulation as a control, which measures the frequency of children's attention, persistence, and other behaviors involving attentional capacity and inhibitory control, and so should have correlated with these other types of executive functions (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Cole, Usher, & Cargo, 1993; Fitzpatrick & Pagani, 2012; Fuhs et al., 2015; Neuenschwander, Rothlisberger, Cimeli, & Roebers, 2012; Riggs, Blair, & Greenberg, 2004).

Study's Contributions and Implications

Our findings support and extend the extant knowledge base. We find that learning difficulties in both reading and mathematics become highly stable as early as the primary grades. This has been reported previously (e.g., Morgan et al., 2009), but often using analyses of smaller-scale convenience samples (e.g., Juel, 1988). Our analyses of the recently released ECLS-K: 2011 data indicate that policymakers, researchers, and practitioners should continue to consider very low levels of academic achievement in either reading or mathematics as highly stable conditions in the general population of U.S. schoolchildren, even by the primary grades. Our results therefore provide additional empirical support for efforts to help children experiencing the early onset of learning difficulties. These screening and intervention efforts likely need to be introduced as early as kindergarten. Factors that might be included in screening efforts to identify children at risk for reading and mathematics difficulties as they age should include family SES, having working memory and cognitive flexibility deficits, displaying lower behavioral self-regulation, and, most importantly, already experiencing either type of learning difficulties—particularly persistently experiencing these difficulties (e.g., Morgan et al., 2009a). These last three types of factors are modifiable through school-based interventions (Dahlin, 2013; Diamond, Barnett, Thomas, & Munro, 2007; Flook et al., 2010; Holmes, Gathercole, & Dunning, 2009; García-Madruga et al., 2013; Riggs, Greenberg, Kusché, Pentz, 2006).

Also consistent with prior work, but again replicated using more recent ECLS-K: 2011 data, our results indicate that only one type of behavioral functioning uniquely increases children's risk for learning difficulties. Specifically, less frequent behavioral self-regulation but not more frequent externalizing or internalizing problem behaviors is predictive of very low levels of academic achievement (e.g., Morgan et al., 2009; Lin et al., 2013). Our analyses of a population-based and longitudinal sample indicate that interventions designed to reduce the frequency of externalizing or internalizing problem behaviors may themselves be unlikely to reduce young children's risk for learning difficulties. Instead, multi-component interventions that also remediate low behavioral self-regulation might be more effective in helping to address learning difficulties.

Our study addresses recently identified limitations in the education field's understanding of the general relation between children's executive function and academic achievement. For example, Jacob and Parkinson (2015) identified only eight studies that accounted for the strong confounds of children's background characteristics when investigating this general relation. The lack of these types of studies has resulted in the extant work being viewed as providing "no compelling evidence" of a causal relation between executive function and academic achievement (Jacob & Parkinson, 2015, p. 30). By designing our study in a way that responded to these identified methodological limitations, our findings contribute to the field's knowledge base by providing stronger preliminary evidence for a potential causal relation between executive functioning deficits and learning difficulties during early childhood. We do so by establishing the executive functioning deficits (a) temporally precede very low levels of achievement in both reading and mathematics and (b) continue to be predictive even with extensive statistical controls for strong potential confounds. Evidence of these two conditions helps to establish that two variables are causally related (Finkel, 1995). Our study internally replicated evidence of this general relation. Specifically, our results indicate that a relation is evident between two specific types of executive functioning deficits and two specific types of learning difficulties, as well as following statistical control for many potential confounds including for the strong confounds of the same- and other-domain autoregressors as well as prior behavioral self-regulation.

In addition to addressing identified methodological limitations in the field's understanding of the general relation between executive functioning deficits and learning difficulties, our study also helps address substantive limitations. This includes the substantive limitation regarding the relative contributions of specific subcomponents of executive function to children's academic achievement. To date, rigorous studies have mostly not included multiple subcomponents of executive function in the same regression analyses (Fitzpatrick & Pagani, 2012; Jacob & Parkinson, 2015). Consequently, it has been unclear which specific subcomponents of executive function are most strongly related to children's academic achievement. This is an important substantive limitation because of the resulting ambiguity regarding which of these subcomponents (e.g., working memory vs. cognitive flexibility) constitutes the most promising target of early interventions efforts to prevent or remediate learning difficulties. Consistent with prior work (e.g., Toll et al., 2011), our study results indicate that, relative to deficits in cognitive functioning, deficits in working memory are more strongly predictive of experiencing learning difficulties during early childhood. Thus, early intervention efforts designed to prevent or remediate learning difficulties may be more effective if they target deficits in working memory than in cognitive flexibility.

An additional substantive limitation of the existing knowledge base has been the lack of rigorous research establishing that executive function is related to both reading and mathematics achievement. For example, Jacob and Parkinson (2015) reported that the currently available studies have not found that executive function was uniquely predictive of both reading and mathematics achievement after covariate adjustment for potential confounds.[2] We find this to be the case. Jacob and Parkinson's (2015) synthesis found only limited evidence that the relation between executive function was stronger for mathematics than for reading achievement. They further reported that neither working memory nor cognitive flexibility displayed a stronger relation with mathematics than for reading achievement. Our study's results help to clarify the nature of these hypothesized causal relations. We find that the relation between executive functioning deficits is relatively stronger for mathematics than for reading difficulties. We also find that working memory deficits increase kindergarten children's risk for reading as well as for mathematics difficulties more strongly than cognitive flexibility deficits.

Conclusion

Results from our analyses of a nationally representative and longitudinal sample indicate that executive functioning deficits are uniquely predictive of kindergarten children's risk for later experiencing learning difficulties. This general relation is evident across two specific types of executive functioning deficits and across two specific types of learning difficulties, as well as following extensive statistical control for strong potential confounds including two types of autoregressors and prior behavioral self-regulation. Working memory deficits are a relatively stronger risk factor for very low academic achievement than cognitive flexibility deficits. Our findings provide empirical support for experimental evaluations of school-based, multi-component interventions designed to address the early onset of learning difficulties through the remediation of executive functioning deficits, particularly in working memory.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Funding for this study was provided to the first author by a Facilitated Project Grant, Penn State's Social Science Research Institute. Infrastructure support was provided by the Penn State Population Research Institute through

[2]This limitation was also evident when Jacob and Parkinson (2015) analyzed the larger group of studies reporting on concurrent rather than a predictive relation between executive functioning and both reading and mathematics achievement. Only one of 11 such studies (i.e., Valiente, Lemery-Chalfant, & Swanson, 2010) reported that executive functioning was concurrently related to both reading and mathematics achievement following covariate adjustment. We emphasize findings from predictive instead of concurrent analyses because the latter provides stronger evidence of potential causality.

funding from the National Institute of Child Health and Human Development, National Institutes of Health (R24HD041025-11). No official endorsement should thereby be inferred.

References

Acock AC. Working with missing values. Journal of Marriage and Family. 2005; 67:1012–1028.

Allison, PD. Missing data. Sage Publications; Thousand Oaks, CA: 2001.

Alloway TP, Gathercole SE, Kirkwood H, Elliott J. The cognitive and behavioral characteristics of children with low working memory. Child Development. 2009; 80:606–621. [PubMed: 19467014]

Andersson U. Working memory as a predictor of written arithmetical skills in children: The importance of central executive functions. British Journal of Educational Psychology. 2008; 78:181–203. doi:http://dx.doi.org/10.1348/000709907X209854. [PubMed: 17535520]

August GJ, Garfinkel BD. Comorbidity of ADHD and reading disability among clinic-referred children. Journal of Abnormal Child Psychology. 1990; 18:29–45. [PubMed: 2324400]

Banich MT. Executive function: the search for an integrated account. Current Directions in Psychological Science. 2009; 18:89–94. http://dx.doi.org/10.1111/j.1467-8721.2009.01615.x.

Blachman BA, Schatschneider C, Fletcher JM, Murray MS, Munger KA, Vaughn MG. Intensive reading remediation in grade 2 or 3: Are there effects a decade later? Journal of Educational Psychology. 2014; 106:46–57. doi: 10.1037/a0033663. [PubMed: 24578581]

Benson JE, Sabbagh MA, Carlson SM, Zelazo PD. Individual differences in executive functioning predict preschoolers' improvement from theory-of-mind training. Developmental Psychology. 2013; 49(9):1615–1627. [PubMed: 23244411]

Brock LL, Rimm-Kaufman SE, Nathanson L, Grimm KJ. The contributions of 'hot'and 'cool' executive function to children's academic achievement, learning-related behaviors, and engagement in kindergarten. Early Childhood Research Quarterly. 2009; 24:337–349.

Budescu DV. Dominance analysis: A new approach to the problem of relative importance of predictors in multiple regression. Psychological Bulletin. 1993; 114:542–551.

Bull R, Espy KA, Wiebe SA. Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. Developmental Neuropsychology. 2008; 33:205–228. doi:http://dx.doi.org/10.1080/87565640801982312. [PubMed: 18473197]

Bull R, Scerif G. Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. Developmental Neuropsychology. 2001; 19:273–293. doi:http://dx.doi.org/10.1207/S15326942DN1903_3. [PubMed: 11758669]

Cain K, Oakhill J, Bryant P. Children's reading comprehension ability: Concurrent prediction by working memory, verbal ability, and component skills. Journal of Educational Psychology. 2004; 96:31–42.

Chapman JW. Learning disabled children's self-concepts. Review of Educational Research. 1988; 58:347–371.

Chetty R, Friedman JN, Hilger N, Saez E, Whitmore Schanzenbach D, Yagan D. How does your kindergarten classroom affect your earnings? Evidence from project STAR. Quarterly Journal of Economics. 2011; 126:1593–1660. [PubMed: 22256342]

Clark CAC, Pritchard VE, Woodward LJ. Preschool executive functioning abilities predict early mathematics achievement. Developmental Psychology. 2010; 46:1176–1191. doi:http://dx.doi.org/10.1037/a0019672. [PubMed: 20822231]

Cole PM, Usher BA, Cargo AP. Cognitive risk and its association with risk for disruptive behavior disorder in preschoolers. Journal of Clinical Child Psychology. 1993; 22:154–164.

Cutuli JJ, Herbers JE, Rinaldi M, Masten AS, Oberg CN. Asthma and behavior in homeless 4-to 7-year-olds. Pediatrics. 2010; 125:145–151. [PubMed: 19969617]

Carlson SM, White RE, Davis-Unger AC. Evidence for a relation between executive function and pretense representation in preschool children. Cognitive Development. 2014; 29:1–16.

Dahlin KI. Working memory training and the effect on mathematical achievement in children with attention deficits and special needs. Journal of Education and Learning. 2013; 2:118–133.

Diamond A, Barnett WS, Thomas J, Munro S. Preschool program improves cognitive control. Science. 2007; 318:1387–1388. [PubMed: 18048670]

Dirks E, Spyer G, van Lieshout EC, de Sonneville L. Prevalence of combined reading and arithmetic disabilities. Journal of Learning Disabilities. 2008; 41:460–473. [PubMed: 18768777]

Duncan GJ, Dowsett CJ, Claessens A, Magnuson K, Huston AC, Klebanov P, Japel C. School readiness and later achievement. Developmental Psychology. 2007; 43:1428–1446. [PubMed: 18020822]

Fisk JE, Sharp CA. Age-related impairment in executive functioning: updating, inhibition, shifting, and access. Journal of Clinical and Experimental Neuropsychology. 2004; 26:874–890. http://dx.doi.org/10.1080/13803390490510680. [PubMed: 15742539]

Fitzpatrick C, Pagani LS. Toddler working memory skills predict kindergarten school readiness. Intelligence. 2012; 40:205–212. doi:http://dx.doi.org/10.1016/j.intell.2011.11.007.

Flanagan, DP., McGrew, KS., Ortiz, SO. The wechsler intelligence scales and gf-gc theory: A contemporary approach to interpretation. Allyn & Bacon; Needham Heights, MA: 2000.

Flook L, Smalley SL, Kitil MJ, Galla BM, Kaiser-Greenland S, Locke J, Kasari C. Effects of mindful awareness practices on executive functions in elementary school children. Journal of Applied School Psychology. 2010; 26:70–95.

Floyd RG, McCormack AC, Ingram EL, Davis AE, Bergeron R, Hamilton G. Relations between the woodcock-johnson III clinical clusters and measures of executive functions from the delis-kaplan executive function system. Journal of Psychoeducational Assessment. 2006; 24:303–317. doi:http://dx.doi.org/10.1177/0734282906287823.

Finkel, SE. Causal analysis with panel data. Sage Publications, Inc; Thousand Oaks, CA: 1995.

Fuhs MW, Farran DC, Nesbitt KT. Prekindergarten children's executive functioning skills and achievement gains. The utility of direct assessments and teacher ratings. Journal of Educational Psychology. 2015; 107:207–221.

García-Madruga JA, Elosúa MR, Gil L, Gómez-Veiga I, Vila JÓ, Orjales I, Duque G. Reading comprehension and working memory's executive processes: An intervention study in primary school students. Reading Research Quarterly. 2013; 48:155–174.

Gathercole SE, Alloway TP, Willis C, Adams A. Working memory in children with reading disabilities. Journal of Experimental Child Psychology. 2006; 93:265–281. [PubMed: 16293261]

Gathercole SE, Durling E, Evans M, Jeffcock S, Stone S. Working memory abilities and children's performance in laboratory analogues of classroom activities. Applied Cognitive Psychology. 2008; 22:1019–1037.

Gathercole, SE., Lamont, E., Alloway, TP. Working memory in the classroom. In: Pickering, SJ., editor. Working memory and education. Elsevier; Oxford, UK: 2006. p. 219-240.

Geary DC. Consequences, characteristics, and causes of mathematical learning disabilities and persistent low achievement in mathematics. Journal of Developmental and Behavioral Pediatrics. 2011; 32:250–263. doi:10.1097/DBP.0b013e318209edef. [PubMed: 21285895]

Geary DC, Hoard MK, Byrd-Craven J, Nugent L, Numtee C. Cognitive mechanisms underlying achievement deficits in children with mathematical learning disability. Child Development. 2007; 78:1343–1359. doi: 10.1111/j.1467-8624.2007.01069.x. [PubMed: 17650142]

Geary DC, Hoard MK, Nugent L, Bailey DH. Mathematical cognition deficits in children with learning disabilities and persistent low achievement: A five-year prospective study. Journal of Educational Psychology. 2012; 104:206–224. [PubMed: 27158154]

Geoffroy M, Côté SM, Giguère C, Dionne G, Zelazo PD, Tremblay RE, Séguin JR. Closing the gap in academic readiness and achievement: The role of early childcare. Journal of Child Psychology and Psychiatry. 2010; 51:1359–1367. doi:http://dx.doi.org/10.1111/j.1469-7610.2010.02316.x. [PubMed: 20883519]

Gresham, PM., Elliot, SN. Social Skills Rating System. American Guidance Service; Circle Pines, MN: 1990.

Han WJ. The academic trajectories of children of immigrants and their school environments. Developmental Psychology. 2008; 44:1572–1590. http://dx.doi.org/10.1037/a0013886. [PubMed: 18999323]

Holmes J, Gathercole SE, Dunning DL. Adaptive training leads to sustained enhancement of poor working memory in children. Developmental Science. 2009; 12:F9–F15. [PubMed: 19635074]

Hooper SR, Roberts J, Sideris J, Burchinal M, Zeisel S. Longitudinal predictors of reading and math trajectories through middle school for African American versus caucasian students across two samples. Developmental Psychology. 2010; 46:1018–1029. doi:http://dx.doi.org./10.1037/a0018877. [PubMed: 20822220]

Jacob R, Parkinson J. The potential for school-based interventions that target executive function to improve academic achievement: a review. Review of Educational Research. 2015; 85:1–41.

Jaffe, LE. Development, interpretation, and application of the W *score and the relative proficiency index*. Riverside Publishing; Rolling Meadows, IL: 2009. Woodcock-Johnson III Assessment Service Bulletin No. 11

Juel C. Learning to read and write: A longitudinal study of 54 children from first through fourth grades. Journal of Educational Psychology. 1988; 80:437–447.

Jyoti DF, Frongillo EA, Jones SJ. Food insecurity affects school children's academic performance, weight gain, and social Skills1-3. The Journal of Nutrition. 2005; 135:2831–2839. [PubMed: 16317128]

Kloo D, Perner J, Kerschhuber A, Dabernig S, Aichhorn M. Sorting between dimensions: Conditions of cognitive flexibility in preschoolers. Journal of Experimental Child Psychology. 2008; 100:115–134. [PubMed: 18241879]

Lehto JE, Juujarvi P, Koolstra L, Pulkkinen L. Dimensions of executive functioning: Evidence from children. British Journal of Developmental Psychology. 2003; 21:59–80. http://dx.doi.org/10.1348/026151003321164627.

Lerner MD, Lonigan CJ. Executive function among preschool children: unitary versus distinct abilities. Journal of Psychopathology and Behavioral Assessment. 2014; 36:626–639. http://dx.doi.org/10.1007/s10862-014-9424-3. [PubMed: 25642020]

Li-Grining C, Votruba-Drzal E, Maldonado-Carreno C, Haas K. Children's early approaches to learning and academic trajectories through fifth grade. Developmental Psychology. 2010; 46:1062–1077. doi:http://dx.doi.org/10.1037/a0020066. [PubMed: 20822223]

Leyva D, Weiland C, Barata M, Yoshikawa H, Snow C, Treviño E, Rolla A. Teacher-child interactions in chile and their associations with prekindergarten outcomes. Child Development. 2015; 86(3): 781–799. [PubMed: 25626642]

Lin Y, Morgan PL, Hillemeier M, Cook M, Maczuga S, Farkas G. Reading, mathematics, and behavioral difficulties interrelate: Evidence from a cross-lagged panel design and population-based sample of US upper elementary students. Behavioral Disorders. 2013; 38:212–227. [PubMed: 26097274]

Locascio G, Mahone EM, Eason SH, Cutting LE. Executive dysfunction among children with reading comprehension deficits. Journal of Learning Disabilities. 2010; 43:441–454. doi:http://dx.doi.org/10.1177/0022219409355476. [PubMed: 20375294]

Masten AS, Herbers JE, Desjardins CD, Cutuli JJ, McCormick CM, Sapienza JK, Zelazo PD. Executive function skills and school success in young children experiencing homelessness. Educational Researcher. 2012; 41:375–384.

Mather, N., Woodcock, RW. Examiner's Manual: Woodcock-Johnson III Tests of Achievement. Riverside Publishing; Itasca, IL: 2001.

Mazzocco MMM. Math learning disability and math LD subtypes: Evidence from studies of turner syndrome, fragile X syndrome, and neurofibromatosis type 1. Journal of Learning Disabilities. 2001; 34:520–533. [PubMed: 15503567]

Miller DP, Waldfogle J, Han WJ. Family meals and child academic and behavioral outcomes. Child Development. 2012; 83:2104–2120. http://dx.doi.org/10.1111/j.1467-8624.2012.01825.x. [PubMed: 22880815]

Miyake A, Friedman N, Emerson M, Witzki A, Howerter A, et al. The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: A latent variable analysis. Cognitive Psychology. 1999; 41:49–100.

Morgan PL, Farkas G, Tufis PA, Sperling RA. Are reading and behavior problems risk factors for each other? Journal of Learning Disabilities. 2008; 41:417–436. doi:http://dx.doi.org/10.1177/0022219408321123. [PubMed: 18768774]

Morgan PL, Farkas G, Wu Q. Kindergarten children's growth trajectories in reading and mathematics: Who falls increasingly behind? Journal of Learning Disabilities. 2011; 44(5):472–488. [PubMed: 21856991]

Morgan PL, Farkas G, Wu Q. Do poor readers feel angry, sad, and unpopular? Scientific Studies of Reading. 2012; 16(4):360–381. [PubMed: 26180489]

Morgan PL, Farkas G, Wu Q. Kindergarten predictors of recurring externalizing and internalizing psychopathology in 3rd and 5th grade. Journal of Emotional and Behavioral Disorders. 2009a; 17:67–79. [PubMed: 26273183]

Morgan PL, Farkas G, Wu Q. Five-year growth trajectories of kindergarten children with learning difficulties in mathematics. Journal of Learning Disabilities. 2009b; 42:306–321. doi:http://dx.doi.org/10.1177/0022219408331037. [PubMed: 19299551]

Murphy MM, Mazzocco MMM, Hanich LB, Early MC. Cognitive characteristics of children with mathematics learning disability (MLD) vary as a function of the cutoff criterion used to define MLD. Journal of Learning Disabilities. 2007; 40:458–478. [PubMed: 17915500]

Naglieri JA, Bornstein BT. Intelligence and achievement: Just how correlated are they? Journal of Psychoeducational Assessment. 2003; 21:244–260. doi:http://dx.doi.org/10.1177/073428290302100302.

National Scientific Council on the Developing Child. Building the brain's "air traffic control" system: How early experiences shape the development of executive function. Harvard University; Cambridge, MA: 2011. Working Paper 11

Neuenschwander R, Rothlisberger M, Cimeli P, Roebers CM. How do different aspects of self-regulation predict successful adaptation to school? Journal of *Experimental Child Psychology*. 2012; 113:353–371. [PubMed: 22920433]

Noël M. Counting on working memory when learning to count and to add: A preschool study. Developmental Psychology. 2009; 45:1630–1643. doi:http://dx.doi.org/10.1037/a0016224. [PubMed: 19899920]

Obradović J. Effortful control and adaptive functioning of homeless children: Variable-focused and person-focused analyses. Journal of Applied Developmental Psychology. 2010; 31:109–117. [PubMed: 20401161]

Parsons S, Bynner J. Numeracy and employment. Education & Training. 1997; 39:43–51. doi:http://dx.doi.org/10.1108/00400919710164125.

Partanen M, Siegel LS. Long-term outcome of the early identification and intervention of reading disabilities. Reading and Writing. 2014; 27:665–684. doi:http://dx.doi.org/10.1007/s11145-013-9472-1.

Pham AV, Hasson RM. Verbal and visuospatial working memory as predictors of children's reading ability. Archives of Clinical Neuropsychology. 2014; 29:467–477. doi:http://dx.doi.org/10.1093/arclin/acu024. [PubMed: 24880338]

Pickering SJ, Gathercole SE. Distinctive working memory profiles in children with special educational needs. Educational Psychology. 2004; 24:393–408.

Riggs NR, Blair CB, Greenberg MT. Concurrent and 2-year longitudinal relations between executive function and the behavior of 1st and 2nd grade children. Child Neuropsychology. 2004; 9:267–276.

Riggs NR, Greenberg MT, Kusché CA, Pentz MA. The mediational role of neurocognition in the behavioral outcomes of a social-emotional prevention program in elementary school students: Effects of the PATHS curriculum. Prevention Science. 2006; 7:91–102. [PubMed: 16572300]

Rivera-Batiz F. Quantitative literacy and the likelihood of employment among young adults in the United States. The Journal of Human Resources. 1992; 27:313–328.

Rohde TE, Thompson LA. Predicting academic achievement with cognitive ability. Intelligence. 2007; 35:83–92.

Rubin, D. Multiple Imputation for Nonresponse in Surveys. Wiley; NY: 1987.

Rubin DB. Formalizing subjective notions about the effect of nonrespondents in sample surveys. Journal of the American Statistical Association. 1977; 72:538–543.

Rubin DB. Multiple imputation after 181 years. Journal of the American Statistical Association. 1996; 91:473–489.

Schulting AB, Malone PS, Dodge KA. The effect of school-based kindergarten transition policies and practices on child academic outcomes. Developmental Psychology. 2005; 41:860–871. doi:http://dx.doi.org./10.1037/0012-1649.41.6.860. [PubMed: 16351333]

Sesma HW, Mahone EM, Levine T, Eason SH, Cutting LE. The contribution of executive skills to reading comprehension. Child Neuropsychology. 2009; 15:232–246. [PubMed: 18629674]

Swanson HL, Beebe-Frankenberger M. 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. 2004; 96:471–491. doi:http://dx.doi.org/10.1037/0022-0663.96.3.471.

Swanson HL, Jerman O, Zheng X. Growth in working memory and mathematical problem in solving in children at risk and not at risk for serious math difficulties. Journal of Educational Psychology. 2008; 100(2):343–379.

Swanson, HL., Sáez, L. Handbook of learning disabilities. Guilford Press; New York, NY: 2003. Memory difficulties in children and adults with learning disabilities; p. 182-198.

Swanson HL, Zheng X, Jerman O. Working memory, short-term memory, and reading disabilities. Journal of Learning Disabilities (Austin). 2009; 42:260–287.

Schmitt SA, McClelland MM, Tominey SL, Acock AC. Strenthening school readiness for head start children: Evaluation of a self-regulation intervention. Early Childhood Research Quarterly. 2015; 30:20–31.

Toll SWM, van der Ven S, Kroesbergen E, van Luit J. Executive functions as predictors of math learning disabilities. Journal of Learning Disabilities. 2011; 44:521–532. [PubMed: 21177978]

Tourangeau, K., Nord, C., Lê, T., Wallner-Allen, K., Hagedorn, MC., Leggitt, J., Najarian, M., U.S. Department of Education. Early Childhood Longitudinal Study, Kindergarten Class of 2010–11 (ECLS-K:2011), User's Manual for the ECLS-K:2011 Kindergarten–First Grade Data File and Electronic Codebook, Public Version (NCES 2015-078). National Center for Education Statistics; Washington, DC: 2015.

Valiente C, Lemery-Chalfant K, Swanson J. Prediction of kindergartners' academic achievement from their effortful control and emotionality: Evidence for direct and moderated relations. Journal of Educational Psychology. 2010; 102:550–560.

Van der Sluis S, de Jong PF, van der Leij A. Inhibition and shifting in children with learning deficits in arithmetic and reading. Journal of Experimental Child Psychology. 2004; 87:239–266. [PubMed: 14972600]

Van der Sluis S, de Jong PF, van der Leij A. Executive functioning in children, and its relations with reasoning, reading, and arithmetic. Intelligence. 2007; 35:427–449. doi:http://dx.doi.org/10.1016/j.intell.2006.09.001.

Van der Ven S,HG, Kroesbergen EH, Boom J, Leseman PPM. The development of executive functions and early mathematics: A dynamic relationship. British Journal of Educational Psychology. 2012; 82:100–119. [PubMed: 22429060]

Wade M, Browne DT, Madigan S, Plamondon A, Jenkins JM. Normal birth weight variation and children's neuropsychological functioning: Links between language, executive functioning, and theory of mind. Journal of the International Neuropsychological Society. 2014; 20:1–11. [PubMed: 24365485]

Watts TW, Duncan GJ, Siegler RS, Davis-Kean P. What's past is prologue: Relations between early mathematics knowledge and high school achievement. Educational Researcher. 2014; 43:352–360. doi:http://dx.doi.org/10.3102/0013189X14553660. [PubMed: 26806961]

White LK, McDermott JM, Degnan KA, Henderson HA, Fox NA. Behavioral inhibition and anxiety: the moderating roles of inhibitory control and attention shifting. Journal of abnormal child psychology. 2011; 39:735–747. [PubMed: 21301953]

Zelazo PD. The Dimensional Change Card Sort (DCCS): A Method of Assessing Executive Function in Children. Nature Protocols. 2006; 1:297–301. [PubMed: 17406248]

Zelazo PD, Anderson JE, Richler J, Wallner-Allen K, Beaumont JL, Conway KP, Weintraub S. NIH toolbox cognition battery (CB): Validation of executive function measures in adults. Journal of the International Neuropsychological Society. 2014; 20:620–629. doi:http://dx.doi.org/10.1017/S135561771400047. [PubMed: 24960301]

Highlights

- Executive functioning deficits in kindergarten uniquely predict reading and mathematics difficulties in first grade
- Executive functioning deficits more strongly predict mathematics difficulties than reading difficulties, although these deficits predict both types of difficulties
- Working memory deficits more strongly predict mathematics and reading difficulties than cognitive flexibility deficits

Table 1

ECLS-K: 2011 Descriptive Statistics (N = 18,080)

	Weighted M	*Weighted SD*	*Unweighted M*	*Unweighted SD*
Executive Function				
Working memory, spring kindergarten	450.86	30.29	449.84	30.39
Cognitive flexibility, spring kindergarten	9.35	2.57	9.26	2.58
Working memory, spring first grade	469.81	25.39	469.38	25.75
Cognitive flexibility, spring first grade	9.32	2.82	8.43	3.12
Academic Achievement				
Reading Test IRT score, spring kindergarten	50.16	11.78	49.56	11.81
Mathematics Test IRT score, spring kindergarten	43.83	11.52	43.38	11.53
Reading Test IRT score, spring first grade	69.94	13.18	69.18	13.21
Mathematics Test IRT score, spring first grade	63.12	13.36	62.51	13.37
Social-demographics				
Male	0.52	0.50	0.51	0.50
Black	0.14	0.34	0.13	0.34
Hispanic	0.25	0.43	0.25	0.43
Asian	0.04	0.20	0.09	0.28
Other race	0.06	0.24	0.06	0.24
Continuous family SES, kindergarten	−0.07	0.77	−0.07	0.81
Household was below poverty line	0.27	0.44	0.28	0.45
Child’s age, fall kindergarten	67.58	4.52	67.46	4.47
Behavioral Functioning				
Teacher-rated behavioral self-regulation, spring kindergarten	3.12	0.68	3.08	0.68
Teacher-rated externalizing problem behaviors, spring kindergarten	1.63	0.62	1.66	0.63
Teacher-rated internalizing problem behaviors, spring kindergarten	1.50	0.48	1.53	0.49
Governmental Assistance, Childcare				
Received food stamps in the past 12 month, spring Kindergarten	0.28	0.45	0.28	0.45
Mother received benefit from WIC when pregnant	0.46	0.50	0.46	0.50
Child received benefit from WIC as an infant or toddler	0.51	0.50	0.51	0.50
Child attended regular center care program	0.70	0.46	0.69	0.46
Household received temporary assistance for needy families	0.05	0.22	0.05	0.23

Note. Weighted data used W4_4P_4TZ0.

Table 2

Logistic Regression Models (Odds Ratio Coefficients) Predicting Reading or Mathematics Difficulties (Lowest 10%), Spring First Grade, ECLS-K: 2011 Data

	Reading Difficulties		*Mathematics Difficulties*	
	Model 1	***Model 2***	***Model 1***	***Model 2***
Executive Functioning Deficits (Spring Kindergarten)				
Working memory deficit	2.66 *	2.17 *	3.38 *	2.87 *
Cognitive flexibility deficit	1.35 *	1.27 *	1.79 *	1.71 *
Prior Learning Difficulties (Spring Kindergarten)				
Reading difficulties	11.15 *	8.77 *	3.37 *	2.77 *
Mathematics difficulties	4.62 *	3.71 *	11.67 *	9.30 *
Socio-demographics				
Gender		1.32 *		0.96
Black		0.90		1.13
Hispanic		1.18		0.96
Asian		0.79		0.54 *
Other race		1.08		1.02
Family SES		0.78 *		0.83 *
Poverty		1.16		1.10
Age		1.07		1.02
Prior Behavioral Functioning (Spring Kindergarten)				
Behavioral self-regulation		0.62 *		0.61 *
Externalizing problem behaviors		0.96		0.95
Internalizing problem behaviors		1.05		1.03
Governmental Assistance, Childcare				
Food stamps (12 months)		1.18		0.99
WIC when pregnant		1.14		1.05
WIC as an infant or toddler		1.00		1.08
Regular center care program		0.98		1.00

	Reading Difficulties		Mathematics Difficulties	
	Model 1	***Model 2***	***Model 1***	***Model 2***
Temporary assistance		1.03		1.09

Note: Executive functioning deficit, learning difficulties defined as scoring in the lowest 10% of the respective measure's distribution; WIC= Special Supplemental Nutrition Assistance Program for Women, Infants, and Children. All continuous variables have been standardized with $M = 0$, $SD = 1$.

* $p <= .05$

** $p <= .01$

*** $p <= .001$.

Table 3

Dominance Analysis for Working Memory Deficit vs. Cognitive Flexibility Deficit Using Nagelkerke's Pseudo R^2 for Model 1 and Model 2 of Reading Difficulties and Mathematics Difficulties

				Additional Contribution	
	Criterion Variables	***Subset Model***	***Psuedo R^2***	***Working Memory Deficit***	***Cognitive Flexibility Deficit***
Model 1	Reading difficulties	All other predictors except deficits in executive function	0.417	0.020	0.002
	Mathematics difficulties	All other predictors except deficits in executive function	0.426	0.031	0.008
Model 2	Reading difficulties	All other predictors except deficits in executive function	0.461	0.012	0.001
	Mathematics difficulties	All other predictors except deficits in executive function	0.461	0.022	0.006