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Executive function deficits in kindergarten predict repeated academic difficulties across elementary school

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ABSTRACT

We investigated whether and to what extent deficits in executive functions (EF) increase kindergarten children's risk for repeated academic difficulties across elementary school. We did so by using growth mixture modeling to analyze the first- through third-grade achievement growth trajectories in mathematics, reading, and science of a large (N = 11,010) sample of children participating in the nationally representative Early Childhood Longitudinal Study-Kindergarten Cohort of 2011 (ECLS-K: 2011). The modeling yielded four growth trajectory classes in mathematics, reading, and science. We observed an at-risk trajectory class in each academic domain using a standardized scale. Children in the at-risk class initially averaged very low levels of achievement (i.e., about two standard deviations below the mean) in first grade. Their trajectories remained very low or declined further by third grade. Trajectories for other classes were also generally flat but started and remained at higher levels of standardized achievement. Deficits in EF, particularly in working memory, increased kindergarten children's risk of experiencing repeated mathematics, reading, and science difficulties across elementary school. These predictive relations replicated across three academic domains following statistical control for domain-specific and -general autoregressors as well as socio-demographic characteristics.

1. Introduction

Academic difficulties often become highly stable by the elementary grades, including in mathematics reading, and science (e.g., Juel, 1988; Morgan, Farkas, & Wu, 2009; Morgan, Farkas, & Wu, 2011; Morgan, Farkas, Hillemeier, & Maczuga, 2016a). Elementary schoolchildren who experience academic difficulties are at increased risk for socio-emotional maladjustment as well as more frequent feelings of anger, anxiety, and peer rejection (Lin et al., 2013; Morgan, Farkas, & Wu, 2012). Identifying factors predictive of domain-general academic difficulties (e.g., in mathematics, reading, and science) should inform efforts to assist children at risk for academic difficulties and so of socio-emotional maladjustment (Blachman et al., 2014; Clark, Pritchard, & Woodward, 2010; Partanen & Siegel, 2014). Such efforts may be especially helpful for children with disabilities who are at high risk for repeated academic difficulties across elementary school (Morgan et al., 2011). Repeated academic difficulties, particularly over several grades, may result from cognitive processing impairments (Geary, 2011) including in executive functions (EF) (Compton, Fuchs, Fuchs, Lambert, & Hamlett, 2012). Children experiencing repeated academic difficulties may therefore require specialized interventions including those remediating cognitive processing impairments.

1.1. Deficits in executive functions as risk factors for repeated academic difficulties

Deficits in EF, or cognitive processing impairments relating to self-regulation, organization, and goal-oriented behavior, have been hypothesized or reported to increase children's risk for academic difficulties, including repeatedly across elementary school (e.g., Bull, Espy, & Wiebe, 2008; Bull & Scerif, 2001; Pham & Hasson, 2014; Pickering & Gathercole, 2004; Swanson & Sáez, 2003; Swanson, Zheng, & Jerman, 2009; Toll, van der Ven, Kroesbergen, & van Luit, 2011; van der Ven, Kroesbergen, Boom, & Leseman, 2012). Children with EF deficits often experience repeated struggles to organize and self-regulate their learning in classroom environments (Geary et al., 2009; Geary, Hoard, Nugent, & Bailey, 2012;

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Peng, Congying, Beilei, & Sha, 2012). Children's EF are considered "inherently malleable" through school-based interventions (Blair, 2016, p. 3).

Three specific types of EF theorized to be related to children's academic achievement are (a) *working memory*, or the ability to hold and then manipulate information during a brief time; (b) *cognitive flexibility*, or the ability to shift attention among multiple aspects of a task as well as update responses using newly acquired information; and (c) *inhibitory control*, or the ability to delay some initial response while attempting to complete a task (Best, Miller, & Jones, 2009; Cantin, Gnaedinger, Gallaway, Hesson-McInnis, & Hund, 2016; Diamond, 2012; Miyake et al., 2000; Monette, Bigras, & Guay, 2011; Monette, Bigras, & Lafrenière, 2015). Inhibitory control grows rapidly during preschool but then slows as children age. In contrast, working memory displays a more linear growth trajectory until adolescence (Best & Miller, 2010). Cognitive flexibility also develops from about age four through adolescence in a linear fashion (Best & Miller, 2010), and may build upon the other two specific types of EF over time (Garon, Bryson, & Smith, 2008; Senn, Espy, & Kaufmann, 2004).

Elementary schoolchildren with deficits in these EF may experience academic difficulties as classroom tasks become more cognitively demanding (Banich, 2009). Working memory deficits are believed to interfere with managing a classroom's information processing and management demands, thereby limiting problem solving and higher-order learning (Jarrold & Towse, 2006). For example, working memory deficits may contribute to difficulties in comprehending text, following multi-step instructions, or effectively using strategies to solve mathematics or science problems (Bull & Scerif, 2001; Viterbori, Usai, Traverso, & de Franchis, 2015). Cognitive flexibility deficits are thought to reduce children's ability to shift their attention across learning tasks (e.g., updating understanding of a text by incorporating new information about a character, adaptively choosing among a set of addition and subtraction strategies to solve a multi-step word problem), resulting in less efficient problem solving, hypothesis generation, and strategic rule use (Bull & Scerif, 2001; Cartwright, 2002; Cartwright et al., 2017; Nayfeld, Fuccillo, & Greenfield, 2013; van der Sluis, de Jong, & van der Leij, 2004; Yeniad, Malda, Mesman, van IJzendoorn, & Pieper, 2013). Inhibitory control deficits are believed to interfere with children's ability to ignore or disregard irrelevant information during classroom activities as well as to down-regulate inattentive, impulsive, or disruptive behaviors (Berry, 2012; Cain, 2006). Inhibitory control deficits should be substantively indistinguishable from effortful control deficits (Allan, Hume, Allan, Farrington, & Lonigan, 2014). This is because effortful control represents "at the trait level many of the cognitive control aspects of EF" (Nigg, 2017, pp. 369−370), with effortful control and EF largely constituting "overlapping constructs" (Eisenberg, 2017, p. 384).

Of the three types of EF deficits, working memory deficits have been hypothesized or reported to be an especially strong risk factor for academic difficulties across multiple domains (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Bull & Lee, 2014; Kudo, Lussier, & Swanson, 2015; Monette et al., 2011; Nutley & Söderqvist, 2017; Rhodes et al., 2016; Ropovik, 2014; Sabol & Pianta, 2012; Swanson et al., 2009) including for children with disabilities (Compton et al., 2012; Gathercole, Alloway, Willis, & Adams, 2006; Kudo et al., 2015; Swanson et al., 2009). Children with working memory deficits are thought to be less able to briefly store as well as manipulate information, which is often required to successfully complete classroom tasks (e.g., decoding, reading comprehension, counting, solving single-digit addition and subtraction problems, following multi-step directions). Working memory deficits, unlike inhibitory control or other types of EF deficits (Rhodes et al., 2016; Swanson, 2011; Swanson & Beebe-Frankenberger, 2004), may also interfere with children's ability to solve problems, think strategically, and engage in higher-order conceptual thinking (Ropovik, 2014). Because problem solving and higher-order thinking become increasingly emphasized across the elementary grades, children with working memory deficits may be especially likely to begin displaying academic difficulties (Bull & Scerif, 2001; Ropovik, 2014; Viterbori et al., 2015). Because they increase children's risk for academic difficulties (Alloway et al., 2009; Gathercole et al., 2008), including repeatedly over several elementary school grades (Bull & Lee, 2014; Stipek & Valentino, 2015; Viterbori et al., 2015), working memory deficits are thought to constitute an especially promising target of early intervention efforts for children with or at risk for disabilities (Peng et al., 2012; Toll et al., 2011).

Inhibitory control or cognitive flexibility deficits may also increase children's risk for repeated academic difficulties. Lower inhibitory control is predictive of lower mathematics achievement even after controlling for strong confounds (Blair & Razza, 2007; Espy et al., 2004; McClelland et al., 2007) including lower working memory (e.g., Bull et al., 2008; Kieffer, Vukovic, & Berry, 2013). Empirical evidence for the risks attributable to cognitive flexibility deficits is somewhat less consistent. Cognitive flexibility deficits have been reported to predict lower academic achievement, although not as strongly as working memory deficits (Morgan et al., 2017). However, other work fails to find that cognitive flexibility deficits are related either concurrently or predictively to academic difficulties (Bull et al., 2008; Epsy et al., 2004). A possible explanation for these mixed findings is that cognitive flexibility deficits begin to limit children's achievement by the later elementary school grades (Best et al., 2009). For example, cognitive flexibility has been reported only to be associated with more advanced academic skills that have yet to be acquired during the primary grades (e.g., Bull & Scerif, 2001).

1.2. Limitations in the extant knowledge base

Limitations in the extant knowledge base have led to ambiguity regarding whether EF deficits are meaningfully related to children's academic difficulties (Clements, Sarama, & Germeroth, 2016; Melby-lervåg & Hulme, 2013; Rapport, Orban, Kofler, & Friedman, 2013) including repeatedly over time (Morgan et al., 2017). Jacob and Parkinson's (2015) synthesis indicated that there was "no compelling evidence" (p. 512) that EF are causally related to children's academic achievement. Clements et al. (2016) stated that "the causal evidence that interventions to develop EF will increase achievement is weak" (p. 86). Identified methodological limitations in the available correlational studies include the use of cross-sectional designs and limited statistical control for other explanatory factors, particularly the strong confounds of sociodemographic characteristics (e.g., lower socioeconomic status, race/ethnicity) and prior academic achievement. These confounds have been hypothesized to fully explain the initially observed relations between EF and children's academic achievement (Jacob & Parkinson, 2015). For example, Jacob and Parkinson (2015) identified only one report (i.e., Fitzpatrick & Pagani, 2012) of a positive and statistically significant predictive relation between EF and achievement following covariate control.

Although some longitudinal work has controlled for prior achievement when estimating whether EF predict children's subsequent achievement (e.g., Blair, Ursache, Greenberg, & Vernon-Feagans, 2015; Fuhs, Nesbitt, Farran, & Dong, 2014; McClelland et al., 2007; Morgan et al., 2017; Seigneuric & Ehrlich, 2005), this has often been done using domain-specific autoregressors (e.g., statistically controlling for prior reading but not also mathematics and science achievement when examining whether children's EF are related to their reading achievement). This is an important methodological limitation because statistical control for domain-specific autoregressors may not sufficiently control for prior achievement confounds. Domain-specific achievement is predicted by both domain-specific and domain-general achievement (Fuchs et al., 2006; Jordan, Hanich, & Kaplan, 2011; Morgan et al., 2016a; Morgan, Farkas, Hillemeier, & Maczuga, 2016b; Morgan et al., 2011). For example, early mathematics achievement is a stronger predictor of later reading achievement than is early reading achievement (Romano, Babchishin, Pagani, & Kohen, 2010). Finding that EF deficits continue to predict children's risk for repeated academic difficulties following statistical control for the strong confounds of both domain-specific and -general autoregressors as well as of socio-demographic characteristics would provide stronger evidence than presently available that EF deficits constitute potentially important targets of early intervention efforts (Jacob & Parkinson, 2015).

An additional methodological limitation of the extant work is that most of the available estimates have analyzed relatively small and less diverse samples (Blair & Razza, 2007; Fuhs et al., 2014; Geary et al., 2012; McClelland et al., 2007; Ponitz, McClelland, Matthews, & Morrison, 2009; Vitiello, Greenfield, Munis, & George, 2011). Despite making many substantive contributions, the generalizability of the reported findings to the heterogeneous U.S. school-aged population is unclear. For instance, Jacob and Parkinson's (2015) synthesis of 67 EF studies reported an average sample size of 237. Some studies have analyzed larger but mostly at-risk samples of children (e.g., Blair & Razza, 2007; Blair et al., 2015; McClelland et al., 2014). Analyzing a large, diverse, and nationally representative sample of U.S. schoolchildren followed across several elementary school grades would clarify whether and to what extent EF deficits predict repeated academic difficulties and, concurrently, provide risk factor estimates with wider generalizability than those currently available. Substantively, few studies have simultaneously estimated whether and to what extent EF deficits are risk factors for repeatedly low academic achievement across multiple academic domains. For example, Morgan et al.'s (2017) analyses only estimated the risk attributable to EF deficits at the end of first grade and did not examine the extent to which such deficits continued to increase children's risk for repeated academic difficulties across elementary school. Yet establishing that EF deficits increase children's risk for repeated domain-general academic difficulties would advance the field's knowledge base. This is because measurement and classification errors for identifying children at risk for academic difficulties are minimized when examining for low academic achievement repeatedly across time rather than at a single period, particularly when done across several measures (Boscardin, Muthén, Francis, & Baker, 2008; Morgan et al., 2016b; Van de Weijer-Bergsma, Kroesbergen, & Van Luit, 2015). Of the relatively few available studies examining early risk factors for repeated academic difficulties, most have examined these relations only for a specific academic domain (e.g., Chong & Siegel, 2008; Lee & Bull, 2016; Lonigan, Allan, & Phillips, 2017; Toll et al., 2011; Van de Weijer-Bergsma et al., 2015; Vukovic, 2012). Whether EF deficits increase the risk for repeated academic difficulties across multiple domains, particularly across several grades as measured in a nationally representative sample, is currently unknown.

Another substantive limitation of the extant work (Jacobs & Parkinson, 2015) is that few studies have included and then contrasted the risk associated with multiple EF deficit types (Blair & Razza, 2007; Clark et al., 2010; Epsy et al., 2004; Lonigan et al., 2017). Instead, relations with achievement have been investigated either between a specific type of EF (e.g., working memory, but not also inhibitory control or cognitive flexibility) (Allan et al., 2014; De Smedt et al., 2009; Yeniad et al., 2013), or with a general indicator of EF (Hassinger-Das, Jordan, Glutting, Irwin, & Dyson, 2014), or for a limited time period (Morgan et al., 2017). It is unclear which of the specific EF deficit types (e.g., working memory vs. cognitive flexibility vs. inhibitory control) most strongly increases the risk for repeated academic difficulties (Jacob & Parkinson, 2015; Raghubar, Barnes, & Hecht, 2010), especially during elementary school (Clark et al., 2010; Epsy et al., 2004). Contrasting the risks associated with each of three specific types of EF deficits would better clarify which specific type may function as the relatively stronger risk factor for repeated academic difficulties across elementary school (Hassinger-Das et al., 2014) and so might constitute a relatively more promising target of intervention. Most of the available studies investigating working memory deficits have examined whether these deficits increase the risk for mathematics difficulties (e.g., Toll et al., 2011). To what extent working memory deficits also increase the risk for reading or science difficulties including over time is less clear (Morgan et al., 2017; Schmitt et al., 2017; Stipek & Valentino, 2015).

1.3. Study's purpose and research questions

We investigated whether and to what extent EF deficits increase kindergarten children's risk of experiencing repeated academic difficulties in mathematics, reading, and science across the elementary school grades. Specifically, we investigated the following research questions.

1. Do EF deficits in kindergarten increase children's risk of experiencing repeated academic difficulties from first to third grade? Are these predictive relations evident across three specific academic domains (i.e., mathematics, reading, and science), replicating the predictive relations and also indicating that EF deficits are domain-general risk factors for repeated academic difficulties? Are these domain-general risks still evident after accounting for strong confounds including domain-specific and -general autoregressors as well as socio-demographic characteristics? Based on prior theoretical and empirical work, we hypothesized that EF deficits would increase the risk for repeated academic difficulties in mathematics, reading, and science, and that these risks would remain evident following covariate adjustment for strong confounds.
2. Among the three specific types of EF deficits, which specific EF deficit is the strongest predictor for repeated academic difficulties across elementary school following statistical control for strong confounds? Based on prior theoretical and empirical work, we hypothesized that working memory deficits would be an especially strong risk factor for repeated academic difficulties when contrasted with the risks associated with cognitive flexibility or inhibitory control deficits.

2. Method

2.1. Database, design, and analytic sample

We analyzed a very large sample ($N = 11{,}010$) of children participating in the Early Childhood Longitudinal Study, Kindergarten Class of 2010–11 (ECLS-K: 2011). The ECLS-K: 2011 (https://nces.ed.gov/ecls/kindergarten2011.asp) dataset is maintained by the U.S. Department of Education's National Center for Education Statistics (NCES) and follows a nationally representative cohort of U.S. children who entered kindergarten in 2010–11. Data from these children are currently available until the spring of third grade.

2.2. Procedures

Field staff from the ECLS-K: 2011 collected data from children, parents, and schools in the fall and spring of kindergarten, the fall and spring of first grade, the fall and spring of second grade, and the spring of third grade. Children's academic achievement in mathematics, reading, and science, as well as their working memory, inhibitory control, and cognitive flexibility abilities were individually assessed during each survey wave. For mathematics and reading achievement, we analyzed data collected from the children in the fall and spring of kindergarten and in the springs of first, second, and third grade. The science assessments were administered across all survey waves except the fall of kindergarten. We examined whether EF deficits identified from fall and spring of kindergarten assessments predicted children's academic achievement trajectories from first to third grade.

2.3. Measures

Children's mathematics, reading, and science achievement were individually assessed using untimed measures based on item response theory (IRT) scaling. Prior to administration of the achievement measures, children in kindergarten or first grade were administered a test of oral English language proficiency. We used this score as a control variable in the analyses. Spanish-speaking children who did not pass the screener were administered the academic achievement assessments in Spanish. The assessments in mathematics, reading, and science were each administered initially using a routing section, which was followed by another section with varying levels of difficulty depending on children's performance on the routing section. Questions were read to the children during both the mathematics and science assessments.

2.3.1. Oral English language proficiency

Kindergarten children completed the first two tasks from the Preschool Language Assessment Scale (*pre*LAS) (Duncan & De Avila, 1998). One was the "Simon Says" task that asked children to follow simple, direct instructions. The second was the "Art Show" task that used a picture vocabulary assessment to measure children's expressive vocabulary. Values on this combination of language assessments ranged from 2 to 20. The score distribution showed a pile-up of values at 20 (i.e., a perfect score), with a long tail stretching out from there to the left. We therefore used a dummy variable with a score at 20 as the reference category (and so suggestive of no language difficulties) and additional dummy variables for each score range (less than 12, 12–15, and 16–19).

2.3.2. Mathematics achievement

Children's mathematics achievement was assessed using the ECLS-K: 2011's Mathematics Test, which included items relating to conceptual knowledge, procedural knowledge, and problem-solving skills. The Mathematics Test from kindergarten to second grade used recommended content from the 2005 NAEP Mathematic Framework, the 2000 National Council of Teachers of Mathematics *Principles and Standards for School Mathematics*, and mathematics standards from five states (i.e., California, New Jersey, Tennessee, Texas, and Virginia). The Mathematics Test for the third graders was developed by comparing multiple standards both at the national and state levels. The Mathematics Test's reliability coefficients ranged from .92 to .94 in kindergarten (Tourangeau et al., 2016).

2.3.3. Reading achievement

The ECLS-K: 2011's Reading Test was designed to assess children's basic reading skills (e.g., print familiarity), vocabulary, and reading comprehension. Children's reading achievement from kindergarten to second grade was assessed using the 2009 NAEP Reading Framework with additional basic reading skills geared towards earlier years of schooling. Beginning in third grade, the ECLS-K: 2011's Reading Test included items from earlier grades and from the 2011 NAEP Reading Framework as well as reading standards from five states (i.e., California, Florida, New Jersey, Texas, and Virginia). Across the survey waves, reliabilities of the IRT-based scores ranged from .87 to .95 (Tourangeau et al., 2016).

2.3.4. Science achievement

The Science Test was designed to assess children's knowledge and understanding of life science (e.g., biology), physical science (e.g., physics), earth and space science, and scientific inquiry. The Science Test's IRT-based scores displayed good reliability, with the coefficients ranged from .75 to .83 across the survey waves (Tourangeau et al., 2016). Items on the Science Test emphasized content included in the science standards of six states (i.e., Arizona, California, Florida, New Mexico, Texas, and Virginia).

2.3.5. Working memory

Children's working memory was measured using the Numbers Reversed subtest of the *Woodcock-Johnson III Tests of Cognitive Abilities* (Woodcock, McGrew, & Mather 2001). The Numbers Reversed task is considered a reliable measure of working memory (Flanagan, McGrew, & Ortiz, 2000), with a reliability coefficient of .87 (Schrank, 2011). During the assessment, children were first orally presented with five two-number sequences (e.g., "1, 3") and then asked to repeat the sequence in reverse order (e.g., "3, 1"). The assessment continued until the maximum of eight-number sequences was completed or three consecutive incorrect responses were given. We used the measure's standardized *W* scores as recommended by the measure's publishers (Mather & Woodcock, 2001). The *W* scale is an equal-interval scale that allows ability level and the difficulty of the items to be measured on the same scale (Jaffe, 2009).

2.3.6. Cognitive flexibility

Children's cognitive flexibility was assessed by the Dimensional Change Card Sort (DCCS; Zelazo, 2006). The DCCS is a well-constructed measure of cognitive flexibility (Zelazo et al., 2013) that has a high test-retest reliability (.90–.94; Beck, Schaefer, Pang, & Carlson, 2011). In the physical version administered from kindergarten to first grade, children were asked to individually sort 22 picture cards following three rules in order: color; shape; and border. Children had to sort four of six cards correctly by shape to proceed to the sorting by border task. All cards with black borders were to be sorted by color, otherwise by shape. A total score was developed by combining scores of all the three tasks. In kindergarten and first grade, the DCCS was administered in Spanish for those who failed to pass the English language screener. Both cognitive flexibility and working memory were assessed using measures of abstract and decontextualized problems with limited emotional or motivational significance.

2.3.7. Inhibitory control

In the fall and spring of kindergarten, teachers were asked to evaluate children's behaviors as naturalistically observed in their classrooms relating to inhibitory control in the past six months using the *Children's Behavior Questionnaire* (CBQ; Putnam & Rothbart, 2006). Items measuring inhibitory control included but were not limited to whether children could easily be distracted or be stopped from doing something as instructed. Teachers assessed children's inhibitory control using a 7-point scale ranging from "extremely untrue" to "extremely true." Higher scores indicated that teachers rated individual children as engaging in the specific behavior more frequently. The Inhibitory Control subscale's reliability coefficient was .87 across the fall and spring of the kindergarten data collections. Allan et al.'s (2014) meta-analysis identified teacher ratings from questionnaires as a preferred type of measure when examining how inhibitory control relates to children's academic achievement.

Table 1
Correlation matrix of executive function variables.

	Cognitive flexibility	Working memory	Inhibitory control
Cognitive flexibility	–		
Working memory	.34	–	
Inhibitory control	.20	.25	–

2.3.8. Socio-demographic characteristics

Gender was first collected from schools during the sampling process and then confirmed during the kindergarten survey parent interviews. Children's race and ethnicity were surveyed during the parent interviews and coded as either White, non-Hispanic; Black, non-Hispanic; Hispanic; Asian; or Other racial or ethnic categories. Age at kindergarten entry was obtained in the fall of kindergarten. Household socioeconomic status (SES) was a composite variable that included information on each parent's or guardian's occupation and educational level as well as the family's household income across kindergarten. Parents were asked whether or not a language other than English was regularly spoken in the home.

2.4. Analytic method

We considered whether the three measures of EF should be included as separate variables in the analyses or combined into a single EF composite measure. Table 1 displays the correlations among the three continuous EF measures. These correlations were relatively modest at .34, .20, and .25. We therefore concluded that they measured different constructs and so kept the measures separate in the analyses. Doing so allowed us to report the risk attributable to each specific type of EF deficit, conditional on other types of EF deficits and additional covariates included in the models.

We transformed the ECLS-K: 2011's Mathematics, Reading, and Science Test scores into *Z*-scores (i.e., $M = 0$, $SD = 1$), separately for each spring assessment in the first-, second-, and third-grade survey waves. We then estimated growth mixture models for each of the three specific academic domains using PROC TRAJ in SAS. This model-based approach allowed us to identify children displaying, relative to other children, repeated academic difficulties across the elementary school grades without relying on arbitrary classification rules. We used the Bayes and the Akaike Information Criterions (BIC, AIC) and the average posterior probabilities of group assignment as well as considering the conceptual and clinical utility of obtained solutions (Nagin, 2005) to evaluate model fit. We used a conventional 5% threshold for the size of the smallest trajectory group so as not to identify groups constituting an overly small percentage of the total population (Nagin, 2005). We selected the models based on (a) those with BIC/AIC values closest to zero, (b) with each group size being at least 5% of the full sample, and (c) with average posterior probabilities of .70 or higher for the groups.

Table 2
Descriptive statistics of selected variables ($N = 11{,}010$).

	Percentage *or M* (*SD*)			
	Total sample	Lowest 10% cognitive flexibility	Lowest 10% working memory	Lowest 10% inhibitory control
Male	51.1%	54.9%	58.3%	72.5%
Kindergarten SES, continuous scale	−0.04 (0.8)	−0.4 (0.7)	−0.5 (0.7)	−0.2 (0.8)
Child age at kindergarten entry, in months	66.2 (4.6)	65.1 (5.1)	68.2 (4.6)	65.7 (4.5)
Child race/ethnicity				
Black	11.0%	18.0%	18.1%	17.3%
Hispanic	26.3%	41.7%	41.7%	24.1%
Asian	7.5%	8.4%	5.0%	5.2%
Other race	5.6%	4.8%	4.1%	4.9%
Reading IRT score				
Fall kindergarten	51.8 (11.4)	45.2 (9.2)	44.6 (7.5)	47.1 (10.2)
Spring kindergarten	66.0 (13.4)	57.2 (11.8)	55.4 (9.5)	58.7 (12.4)
Spring first grade	89.6 (16.3)	78.2 (16.5)	74.8 (14.5)	78.8 (17.3)
Spring second grade	102.6 (13.4)	92.9 (14.5)	89.8 (13.7)	93.7 (15.7)
Spring third grade	110.4 (12.3)	101.0 (13.3)	98.4 (12.8)	102.6 (14.7)
Math IRT score				
Fall kindergarten	34.0 (11.7)	25.1 (9.5)	24.6 (7.7)	28.2 (10.9)
Spring kindergarten	47.9 (12.5)	37.1 (11.5)	36.3 (9.9)	40.6 (12.9)
Spring first grade	70.8 (16.6)	56.9 (15.9)	54.6 (14.3)	60.6 (18.0)
Spring second grade	86.8 (15.4)	73.2 (17.7)	70.9 (16.8)	77.3 (19.3)
Spring third grade	97.8 (14.2)	85.7 (16.1)	83.6 (15.1)	89.8 (16.8)
Science IRT score				
Spring kindergarten	31.1 (7.0)	25.6 (6.2)	25.9 (5.8)	28.6 (7.0)
Spring first grade	39.5 (10.2)	31.3 (8.2)	31.5 (7.8)	35.6 (10.0)
Spring second grade	47.7 (10.3)	38.6 (10.6)	38.6 (9.7)	43.0 (11.1)
Spring third grade	54.9 (10.0)	46.5 (10.3)	45.8 (9.7)	50.4 (11.0)
Working memory				
Fall kindergarten	93.5 (16.9)	83.8 (14.3)	71.3 (8.0)	87.6 (15.6)
Spring kindergarten	95.6 (16.9)	84.2 (15.9)	67.9 (7.1)	87.7 (16.8)
Cognitive flexibility				
Fall kindergarten	14.3 (3.2)	7.8 (3.6)	12.6 (4.0)	13.4 (3.8)
Spring kindergarten	15.2 (2.7)	11.0 (4.3)	13.8 (3.5)	14.5 (3.3)
Inhibitory control				
Fall kindergarten	5.0 (1.2)	4.5 (1.3)	4.5 (1.3)	2.7 (0.7)
Spring kindergarten	5.1 (1.2)	4.7 (1.3)	4.7 (1.3)	2.8 (0.7)
Oral language score	19.1 (2.1)	17.8 (3.3)	17.9 (3.5)	18.8 (2.4)
Non-English spoken at home	3.6%	4.4%	4.4%	2.9%

Note: IRT = item response theory; SES = socioeconomic status.

We estimated linear and quadratic models for each of the three achievement domains.

We then used multinomial logistic regression with clustered standard errors to predict whether deficits in cognitive flexibility, working memory, or inhibitory control during kindergarten, as indicated by being in the lowest 10% of scores in kindergarten averaged across fall and spring on any of the three EF measures, predicted membership in the mathematics, reading, and science achievement trajectory classes. A 10% cut-off to identify children displaying EF deficits is consistent with prior empirical work (e.g., Alloway et al., 2009; Brooks et al., 2006; Nigg, Willcutt, Doyle, & Sonuga-Barke, 2005). Use of both the fall and spring of kindergarten time points to identify those with EF deficits helped to minimize random measurement error (Boscardin et al., 2008; Van de Weijer-Bergsma et al., 2015). As a robustness check, we re-estimated the same multinomial logistic regression models using a less restrictive 25% cut-off for cognitive flexibility, working memory, or inhibitory control deficits (Colvert et al., 2008; Morgan et al., 2017). Specifically, and in our robustness check, we operationalized each specific EF deficit as being in the lowest 25% during both the fall and spring of kindergarten of the respective assessment distributions. We estimated these predictive relations while also statistically controlling for children's socio-demographic characteristics as well as lagged (i.e., spring of kindergarten) mathematics, reading, and science achievement. Such autoregressors control for time-invariant confounds. After conducting these multinomial logistic regression analyses, we performed Wald tests for the equality of coefficients to compare the predictive strengths of the three different types of EF deficits.

3. Results

Table 2 displays the full analytic sample's descriptive statistics as well as statistics for children scoring in the lowest 10% on the measures of cognitive flexibility, working memory, and inhibitory control. For each group, this includes the means for the mathematics, reading, and science IRT-scores from the ECLS-K: 2011's measures at each survey wave. We converted these IRT-scores into *Z*-scores separately for each of the survey waves. This allowed us to examine which trajectory groups displayed achievement either above or below the overall group average at a particular time period. The estimated trajectories for these groups therefore describe relative academic achievement.

3.1. *Estimating children's first through third grade academic achievement trajectories*

Table 3 shows the goodness-of-fit AIC and BIC values for linear and quadratic models with varying numbers of trajectory classes for mathematics, reading, and science. Because the models with five or six trajectory groups had some groups with less than 5% of the full sample, we selected models with four trajectory groups. Because the goodness-of-fit measures for the linear models were close to those of the quadratic models, we selected the linear models for their greater simplicity. The average posterior probabilities of class membership ranged from .90 to .95 for mathematics, from .88 to .95 for reading, and from .89 to .92 for science and so indicated a high degree of classification precision in the models. Figs. 1–3 display the resulting achievement trajectory groups for mathematics, reading, and science, respectively.

Fig. 1's Group 1 constituted 6% of the sample. This group averaged mathematics achievement two standard deviations below the mean in first grade that then declined further from the mean in second and third grade. Group 2 constituted 25% of the sample and averaged almost one standard deviation below the mean in first grade and then remained at about this level in second and third grade. Group 3, which was 39% of the sample, scored close to the mean in first grade and then increased subsequently to about 0.2 standard deviations above the mean by third grade. Group 4, which was about 30% of the sample, averaged about one standard deviation above the mean in first grade and about one standard deviation above the mean by third grade.

Table 3
Akaike and Bayes information criterion values for the mathematics, reading, and science achievement growth mixture modeling.

Number of groups	Linear		Quadratic	
	AIC	BIC	AIC	BIC
Mathematics				
2	−38,978	−39,000	−38,975	−39,004
3	−35,084	−35,117	−35,042	−35,086
4	−32,713	−32,757	−32,581	−32,639
5	−31,693	−31,748	−31,481	−31,554
6	−31,052	−31,118	−30,763	−30,851
Reading				
2	−39,538	−39,560	−39,538	−39,567
3	−35,415	−35,448	−35,335	−35,378
4	−33,565	−33,608	−33,486	−33,544
5	−32,536	−32,591	−32,423	−32,496
6	−32,130	−32,196	−31,990	−32,078
Science				
2	−39,701	−39,723	−39,700	−39,729
3	−36,331	−36,364	−36,314	−36,358
4	−34,589	−34,633	−34,548	−34,606
5	−33,723	−33,778	−33,661	−33,734
6	−33,338	−33,404	−33,257	−33,344

Note. AIC = Akaike information criterion; BIC = Bayes information criterion.

Figs. 2 and 3 show similar group trajectory patterns for the reading and science achievement trajectories, respectively. For reading, Group 1 (about 7% of the sample) began about two standard deviations below the mean. For science, Group 1 (about 14% of the sample) began 1.3 standard deviations below the mean and then declined further over time. For reading and science, Groups 2 and 3 began below and above the mean, respectively, and remained relatively constant through third grade. For both reading and science, Group 4 began at or above one standard deviation above the mean and continued at this relative level or declined somewhat.

Across Figs. 1–3 and so for each academic domain, children in Groups 1 and 2 displayed repeated academic difficulties. Group 1 children were of particular concern due to their especially severe levels of academic difficulties averaging about 1.5 or more standard deviations below the mean at each time point. We next estimated multinomial regression models that predicted the odds of membership in each of these groups as compared with a base category of typically developing children (i.e., Group 3). Table 4 shows these results for mathematics achievement. Tables 5 and 6 show these results for reading and science achievement, respectively.

3.2. *Do EF deficits in kindergarten predict repeated mathematics difficulties from first to third grade?*

Table 4's Model 1 predicted children's membership in each of the mathematics trajectory groups using only dummy variables indicating membership in the lowest 10% of each of the three EF measures as predictors. Model 2 added the domain-specific and -general achievement autoregressors of kindergarten children's mathematics, reading, and science achievement. Model 3 added the child's age, race/ethnicity, gender, family SES, kindergarten oral language (as represented by three dummy variables) and whether or not a language other than English was spoken at home as additional controls.

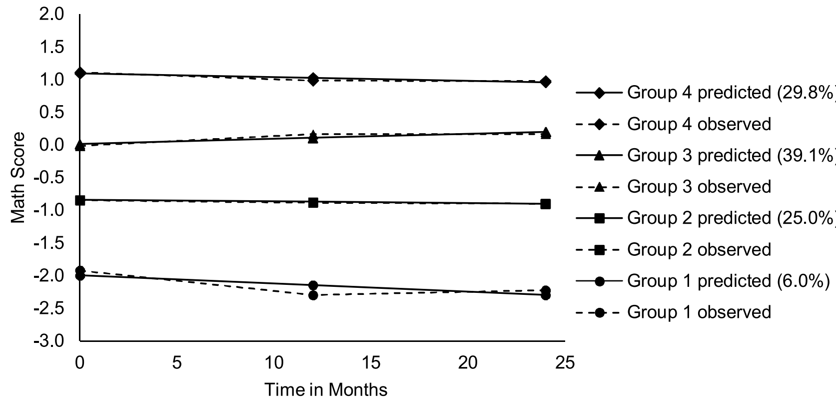

Fig. 1. Trajectories of math scores (standardized at each time point) for first through third grade.

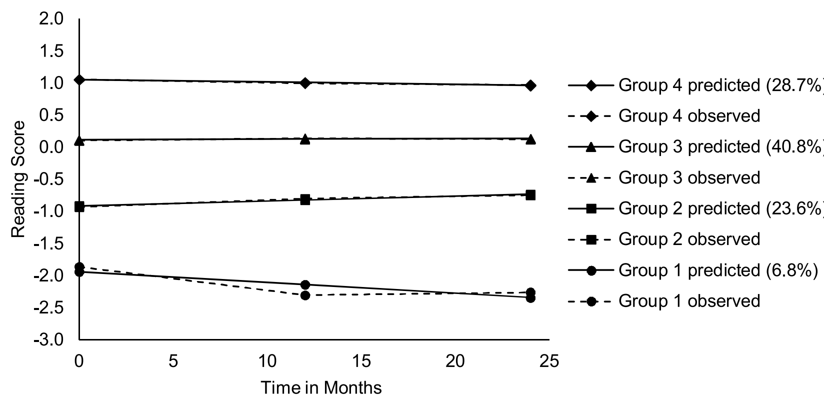

Fig. 2. Trajectories of reading scores (standardized at each time point) for first through third grade.

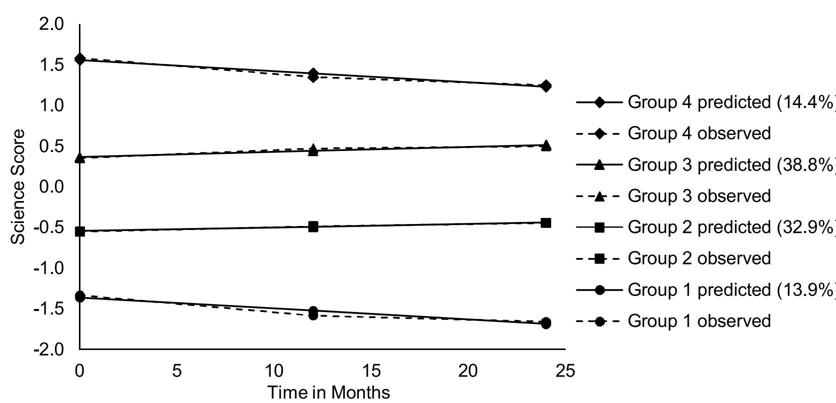

Fig. 3. Trajectories of science scores (standardized at each time point) for first through third grade.

Table 4's Model 1 shows that cognitive flexibility, working memory, or inhibitory control deficits significantly predicted the odds of membership in Groups 1, 2, and 4 versus Group 3. Among the three types of EF deficits, working memory deficits were the strongest predictor of membership in Group 1's repeated mathematics difficulties trajectory. Specifically, kindergarten children whose working memory scores were in the lowest 10% had odds of being in the Group 1 versus Group 3 trajectory class that were greater by a multiplicative factor of 10.10 ($p < .001$). Working memory deficits in kindergarten multiplied the odds of Group 2 versus Group 3 membership by a factor of 3.97 ($p < .001$) and predicted decreased odds of membership in the highest achieving Group 4 versus Group 3 by a multiplicative factor of 0.21 (i.e., 1–.21, or a 79% difference in relative odds). Model 1 indicated significant but less strong predictive relations for deficits in cognitive flexibility and inhibitory control.

Table 4's Model 2 shows that statistically controlling for kindergarten children's academic achievement (i.e., simultaneously controlling for domain-specific lagged mathematics as well as domain-general lagged reading, and science achievement) partially explained Model 1's predictive relations between EF deficits in kindergarten and children's first-through-third grade mathematics achievement trajectories. Higher mathematics achievement in kindergarten predicted reduced odds of membership in Group 1's mathematics achievement trajectory by 29% (1–.71). Higher mathematics achievement in kindergarten also predicted a decrease in the odds of membership in the Group 2 versus Group 3 trajectory. However, and despite the domain-specific and -general autoregressive achievement controls, working memory deficits continued to predict an almost five-fold (adjusted $OR = 4.79$, $p < .001$) increase in the odds of Group 1 membership, and an approximate doubling

Table 4
Multinomial logistic predictors of math trajectory group membership from first to third grade (odds ratios).

	Group 1			Group 2			Group 4		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Kindergarten executive function deficit									
Cognitive flexibility	7.10***	1.81***	1.82***	2.54***	1.20*	1.24*	0.35***	0.76	0.72
Working memory	10.10***	4.79***	4.97***	3.97***	2.32***	2.32***	0.21***	0.63*	0.70
Inhibitory control	4.89***	2.28***	2.24***	1.94***	1.38***	1.49***	0.73**	1.15	0.93
Kindergarten academic achievement									
Reading score		0.96**	0.95***		1.00	0.99		1.00	1.01
Mathematics score		0.71***	0.71***		0.84***	0.84***		1.21***	1.22***
Science score		0.93***	0.93***		0.95***	0.96***		1.05***	1.03***
Child age at K entry			1.00			1.01			0.97***
Child race/ethnicity									
Black			3.51***			3.02***			0.24***
Hispanic			0.77			1.12			0.74**
Asian			0.34**			0.66*			1.07
Other race			1.45			1.24			1.14
Male			0.68**			0.66***			2.43***
SES			0.89			0.86**			1.26***
Oral language score									
Oral language < 12			2.21			1.29			0.14***
Oral language 12–15			0.80			0.72*			1.10
Oral language 16–19			1.30			0.98			0.92
Non-English spoken at home			0.63			0.72			1.37

Note. N = 11,010. Group 3 was used as the reference group. K = kindergarten; SES = socioeconomic status.
*p < .05. **p < .01. ***p < .001.

(adjusted OR = 2.32, p < .001) of the odds of Group 2 versus Group 3 membership.

Model 3 added children's socio-demographic characteristics, kindergarten oral language proficiency, and speaking a language other than English at home as additional statistical controls. Several of the covariates showed strong predictive relations with the mathematics achievement trajectory groupings. Children who are Black were particularly likely to be members of the two lowest mathematics achievement trajectory groups. Children who are Asian or male were particularly unlikely to be members of these same trajectories. Black and Hispanic children had reduced odds of being in the highest achieving Group 4. Males and children from higher SES families had increased odds of membership in Group 4 compared with Group 3. However, adding these socio-demographic characteristics as statistical controls had relatively little effect on the risks associated with EF deficits. Instead, the coefficients for EF deficits were quite similar in magnitude across Models 2 and 3. Overall, deficits in cognitive flexibility, working memory, or inhibitory control by kindergarten each predicted a greater risk for repeated mathematics difficulties across first to third grade. Of these three specific types of EF, the strongest observed predictive relations were for working memory deficits (adjusted OR of 4.97, p < .001). Wald tests indicated that the magnitude of this effect was significantly larger than that of cognitive flexibility or inhibitory control deficits.

3.3. *Do EF deficits in kindergarten predict repeated reading difficulties from first to third grade?*

As displayed in Table 5, we observed similar results when predicting membership in the four reading achievement trajec-

Table 5
Multinomial logistic predictors of trajectory group membership of reading achievement from first to third grade (odds ratios).

	Group 1			Group 2			Group 4		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Kindergarten executive function deficit									
Cognitive flexibility	3.84***	0.94	0.93	2.29***	1.10	1.09	0.37***	0.77	0.80
Working memory	7.11***	3.41***	2.83***	3.29***	2.04***	1.88***	0.13***	0.36***	0.43***
Inhibitory control	4.79***	2.65***	2.29***	2.16***	1.70***	1.58***	0.59***	0.75*	0.81
Kindergarten academic achievement									
Reading score		0.76***	0.77***		0.87***	0.87***		1.12***	1.12***
Mathematics score		0.86***	0.86***		0.95***	0.95***		1.05***	1.05***
Science score		0.98	0.98		0.97***	0.97***		1.09***	1.09***
Child age at K entry			1.02			1.00			0.97***
Child race/ethnicity									
Black			0.84			1.03			0.64**
Hispanic			0.66*			0.83*			1.04
Asian			0.25***			0.57***			0.93
Other race			0.90			0.75*			1.14
Male			2.05***			1.33***			0.76***
SES			0.58***			0.81***			1.24***
Oral language score									
Oral language < 12			1.63			1.37			0.64
Oral language 12–15			1.17			1.03			1.45
Oral language 16–19			1.14			1.09			0.88
Non-English spoken at home			0.74			1.19			1.34

Note. N = 11,010. Group 3 was used as the reference group. K = kindergarten SES = socioeconomic status.
*p < .05. **p < .01. ***p < .001.

Table 6
Multinomial logistic predictors of trajectory group membership of science achievement from first to third grade (odds ratios).

	Group 1			Group 2			Group 4		
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
Kindergarten executive function deficit									
Cognitive flexibility	7.85 ***	1.98 ***	1.93 ***	2.52 ***	1.30 *	1.31 *	0.36 ***	0.73	0.73
Working memory	8.32 ***	2.49 ***	2.27 ***	3.04 ***	1.40 **	1.32 **	0.20 ***	0.74	0.77
Inhibitory control	2.59 ***	1.23	1.40 *	1.42 ***	1.00	1.08	0.69 **	1.01	0.97
Kindergarten academic achievement									
Reading score		0.93 ***	0.92 ***		0.97 ***	0.96 ***		1.03 ***	1.02 ***
Mathematics score		0.88 ***	0.89 ***		0.94 ***	0.95 ***		1.07 ***	1.06 ***
Science score		0.68 ***	0.70 ***		0.83 ***	0.84 ***		1.22 ***	1.21 ***
Child age at K entry			1.01			1.01			0.99
Child race/ethnicity									
Black			4.97 ***			2.70 ***			0.59 **
Hispanic			1.09			1.12			1.00
Asian			0.62			0.87			0.97
Other race			0.87			0.95			1.22
Male			0.54 ***			0.69 ***			1.34 ***
SES			0.75 ***			0.86 ***			1.44 ***
Oral language score									
Oral language < 12			2.87 ***			1.49 *			1.08
Oral language 12–15			1.60 ***			1.22 **			0.79
Oral language 16–19			1.00			1.00			1.00
Non-English spoken at home			0.77			0.87			1.86*

Note. $N = 11{,}010$. Group 3 was used as the reference group. K=kindergarten; SES = socioeconomic status.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

tory groupings. In Model 1, EF deficits significantly and positively predicted membership in the lower reading achievement groups (i.e., Groups 1 and 2), as well as significantly and negatively predicted membership in the higher reading achievement group (i.e., Group 4). As with mathematics, and among the three specific types of EF deficits, the strongest predictive relation was for working memory deficits. As also with mathematics, controlling for domain-general academic achievement but not additionally controlling for socio-demographic characteristics (i.e., Model 2) substantially reduced the size of the predictive relations between each of the three specific types of EF deficits in kindergarten and membership in the reading achievement trajectory groups. Unlike for working memory or inhibitory control deficits, statistical control for domain-general academic achievement fully explained the initially observed relations between cognitive flexibility deficits and children's reading achievement trajectories. Model 3 indicated that working memory and inhibitory control deficits predicted membership in the lowest reading achievement trajectory group following covariate adjustment. Kindergarten children with working memory deficits had odds of Group 1 membership that were 2.83 times ($p < .001$) higher than otherwise similar kindergarten children without working memory deficits. Inhibitory control deficits increased the odds of Group 1 membership relative to Group 3 by over two times (adjusted $OR = 2.29$, $p < .001$), but their predictive strength was significantly smaller than that of working memory deficits.

3.4. Do EF deficits in kindergarten predict repeated science difficulties from first to third grade?

Table 6 repeats the analyses for membership in the four science achievement trajectory groupings. Model 1 shows that EF deficits significantly predicted repeated science difficulties. The strongest of these relations was again for working memory deficits. Kindergarten children with working memory deficits were especially unlikely to belong to the highest achieving group (i.e., Group 4). After controlling for domain-specific and -general academic achievement and children's socio-demographic characteristics in Model 3, EF deficits generally remained significant predictors of lower science achievement trajectories. Kindergarten children with working memory deficits were more than twice as likely to display repeated science difficulties (adjusted *OR* of 2.27, $p < .001$) than kindergarten children without working memory deficits. We observed a similarly strong relation for cognitive flexibility deficits (adjusted *OR* of 1.93, $p < .001$). We observed a smaller relation for inhibitory control deficits (adjusted *OR* of 1.40, $p < .05$). However, the Wald test did not reject the null hypothesis of equality of coefficients.

3.5. Robustness check

We re-estimated these multinomial logistic regression models using a less restrictive operationalization (i.e., being in the lowest 25% during both the fall and spring of kindergarten distributions) of cognitive flexibility, working memory, or inhibitory control deficits (results available from the study's first author). We again found that working memory deficits increased children's risk of repeated academic difficulties in mathematics, reading, and science achievement. Children with working memory deficits were more likely to be in the lowest achievement trajectory group relative to the typically developing group, with estimated covariate-adjusted odds ratios of 3.96, 2.67, and 1.84 (each $p < .001$) for mathematics, reading, and science, respectively.

3.6. Additional risk factors for repeated academic difficulties

Additional risk factors for repeated academic difficulties included a lower level of prior achievement in the specific (e.g., mathematics) as well as general domains (i.e., reading, science), race/ethnicity, and gender. Males were more likely than females to experience repeated academic difficulties in reading but less likely to experience repeated academic difficulties in mathematics or science. Children from higher SES families were less likely to experience repeated academic difficulties.

4. Discussion

We used growth mixture modeling to examine the mathematics, reading, and science achievement trajectories of a large, nationally representative sample of kindergarten children followed from first to third grade. For each academic domain, the modeling yielded an at-risk growth trajectory that began and remained far below the overall average achievement level. We then investigated whether and to what extent EF deficits increased the risk of experiencing each of these types of achievement trajectories, including a trajectory indicative of repeated academic difficulties from first to third grade. We consistently observed that EF deficits—particularly in working memory—increased kindergarten children's risk for repeated academic difficulties. For example, kindergarteners with working memory deficits had covariate-adjusted odds of experiencing the lowest achievement trajectories in mathematics, reading, or science that were 5.0, 2.8, and 2.3 times higher, respectively, than those of otherwise similar kindergarten children without working memory deficits. Deficits in cognitive flexibility and inhibitory control also predicted an increased risk of repeated academic difficulties across elementary school. We replicated these predictive relations for three academic domains before and after extensive statistical control for both domain-specific and -general autoregressors and socio-demographic characteristics. These covariates themselves strongly predicted the achievement trajectories. Collectively, our findings suggest that EF deficits by kindergarten increase the risk for domain-general repeated academic difficulties across elementary school. These increased risks were robust to an alternative EF deficit operationalization.

4.1. Limitations

Data from the ECLS-K: 2011 are currently available only through the third grade. We were therefore unable to investigate whether the observed predictive relations between EF deficits and children's achievement trajectories were evident during middle or high school. Deficits in working memory or other types of EF may become less of a risk factor for repeated academic difficulties as children age (Lee & Bull, 2016; Stipek & Valentino, 2015), possibly as a result of domain-specific knowledge as well as peer-based feelings of academic competency becoming more important as contributors to achievement. The risks associated with EF deficits other than in working memory may increase over time as classroom academic content becomes increasingly abstract and complex (Purpura, Schmitt, & Ganley, 2017).

Working memory and cognitive flexibility were directly and independently assessed by the ECLS-K: 2011's field staff, while children's inhibitory control was indirectly assessed using teacher ratings. Although teacher ratings are a preferred method for assessing inhibitory control (Allan et al., 2014) and are as strongly associated with children's achievement as direct assessments, measurement error in the inhibitory control assessment may somewhat attenuate our estimates. Although preferable, the ECLS-K: 2011's very large sample size, multiyear timeframe, and extensive measurement of a wide range of factors precluded multiple measures of children's working memory, cognitive flexibility, and inhibitory control. We were unable to directly control for IQ as well as additional factors that may be related to children's achievement trajectories. However, our inclusion of both domain-specific and -general autoregressors as well as oral language should have accounted for unmeasured time-invariant confounds including IQ.

The study's estimates are not causal. Instead, the estimates indicate that EF deficits during kindergarten increase the risk for repeated academic difficulties in mathematics, reading, or science from first to third grade, and that these increased risks are not explained by other factors including other types of EF deficits, domain-specific or -general autoregressors of prior achievement, or socio-demographic characteristics. Experimental studies are needed to unambiguously establish whether remediating EF deficits increases children's academic achievement during elementary school. Whether EF training increases children's academic achievement, including for those with disabilities, is currently unclear due to methodological limitations in the available experimental work (Jacob & Parkinson, 2015; Kirk, Gray, Riby, & Cornish, 2015; Melby-lervåg & Hulme, 2013; Rapport et al., 2013; Rode, Robson, Purviance, Geary, & Mayr, 2014; Titz & Karbach, 2014).

4.2. Study's contributions and implications

Deficits in EF have been hypothesized or reported to increase elementary school children's risk for academic difficulties (Alloway et al., 2009; Morgan et al., 2017), including repeatedly throughout elementary school (Toll et al., 2011). Repeated academic difficulties have been theorized to result from deficits in specific cognitive processes including in EF (Compton et al., 2012; Geary, 2011). Working memory deficits have been hypothesized or reported to interfere with children's problem solving, strategic thinking, and higher-order conceptual understanding (Ropovik, 2014) by constraining their ability to manage the continual storage and processing demands of classrooms (Bull & Scerif, 2001; Viterbori et al., 2015). Cognitive flexibility deficits may result in children being less able to productively shift their attention while working on classroom tasks (e.g., following a teacher's multi-step directions, applying new information about a character to infer meaning in a text), thereby constraining the ability to problem solve and strategically use rules (Cartwright et al., 2017; Nayfeld et al., 2013; Yeniad et al., 2013). Inhibitory control deficits may limit children's ability to ignore or disregard irrelevant information as well as to down-regulate inattentive, impulsive, or disruptive behaviors that may interfere with academic achievement (Berry, 2012; Cain, 2006).

Yet whether and to what extent EF deficits increase children's risk for repeated academic difficulties across elementary school has been unclear (Morgan et al., 2017). For example, substantive and methodological limitations in the available correlational (Clements et al., 2016; Jacob & Parkinson, 2015) as well as experimental work (Melby-lervåg & Hulme, 2013; Rapport et al., 2013; Titz & Karbach, 2014) have resulted in ambiguity as to whether EF deficits are meaningfully related to children's academic difficulties (Jacob & Parkinson, 2015). The available correlational work has been criticized as relying mostly on cross-sectional designs, insufficiently controlling for potential confounds including socio-demographic characteristics and children's prior academic achievement (Clements et al., 2016; Jacob & Parkinson, 2015), and using convenience or homogeneous samples of limited generalizability (Schmitt et al., 2017). The extant reading and mathematics disabilities studies have also been criticized for being based on samples with limited generalizability (Kudo et al., 2015; Lewis & Fisher, 2016). Few studies have investigated whether EF deficits increase the risk for repeated academic difficulties including as measured across several grade levels and across multiple academic domains (Morgan et al., 2017; Toll et al., 2011).

By addressing these methodological and substantive limitations in the extant correlational work, our study makes several important contributions. Methodologically, we show that EF deficits temporally precede children's academic difficulties as well as continue to predict these difficulties after accounting for strong confounds including domain-specific and -general autoregressive achievement as well as socio-demographic characteristics. This extends prior correlational work that has largely been limited to reporting that EF deficits predict greater risk for either repeated academic difficulties but only in a single domain (Geary et al., 2012; Toll et al., 2011) or for multiple types of academic difficulties but only as measured at a single time period (Morgan et al., 2017). By analyzing a nationally representative sample followed over a multiyear time frame, our analyses provide risk estimates with wider generalizability than those currently available regarding the risk factors for repeated academic difficulties across elementary school. Our use of growth mixture modeling and multiple indicators of achievement should have minimized measurement and classification errors and so provided more accurate risk estimates (Boscardin et al., 2008; Lewis & Fisher, 2016).

Substantively, our analyses contribute to the currently limited empirical knowledge base regarding which of the three specific EF deficits may be most strongly related to children's risk of experiencing repeated academic difficulties across elementary school. By including multiple measures of EF as well as many covariates including both oral language skill and domain-specific and -general autoregressors, our study helps to address the impurity problem often encountered in studies of EF (i.e., in which each EF partially overlaps with other EF or cognitive processes). Our study also helps clarify that, in contrast to cognitive flexibility or inhibitory control deficits, working memory deficits are an especially strong risk factor for repeated academic difficulties including over several elementary grades (Friso-van den Bos et al., 2013). Our study also helps to establish that working memory deficits constitute a general risk factor for repeated academic difficulties across elementary school, with this increased risk evident whether for mathematics, reading, or science difficulties. Whether working memory deficits increase the risk for repeated reading and science as well as mathematics difficulties has been unclear (Morgan et al., 2017; Schmitt et al., 2017; Toll et al., 2011). We find this to be the case. Relations between children's EF and their science achievement have rarely been investigated (Nayfeld et al., 2013). Our study contributes to this very limited knowledge base by estimating the risk associated with each of three types of EF deficit on children's later science achievement. These estimates have previously been unavailable (Morgan et al., 2017). Working memory deficits are a stronger risk factor for repeated mathematics or reading difficulties than either cognitive flexibility or inhibitory control deficits. These findings replicate and also extend Morgan et al.'s (2017) recent analyses that found that working memory and cognitive flexibility deficits increased the risk for reading and mathematics difficulties, with the risks particularly strong for mathematics difficulties and for working memory deficits, but only as assessed at the end of first grade and so neither for science difficulties nor for repeated academic difficulties across elementary school. Our work helps empirically establish that children experiencing repeated academic difficulties may have specific cognitive deficits including in EF. These children may benefit from specialized interventions that remediate these cognitive processing deficits (Geary, 2011).

Consequently, and consistent with other correlational work (Schmitt et al., 2017; Stipek & Valentino, 2015; Toll et al., 2011), our analyses suggest that experimentally evaluated interventions designed to remediate both EF and academic skills deficits during kindergarten might be expected to be more effective in reducing children's risk for repeated academic difficulties than interventions designed only to remediate academic skills deficits including across multiple academic domains. This is because repeated academic difficulties in mathematics, reading, or science may also be resulting from deficits in specific cognitive processes rather than only from academic skills deficits. Consequently, our results suggest that school-based efforts that effectively identify and assist kindergarten children experiencing EF deficits, particularly in working memory, may help lessen these children's subsequent risk for repeated academic difficulties across elementary school.

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