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Preschool Intervention Can Promote Sustained Growth in the Executive-Function Skills of Children Exhibiting Early Deficits

Tyler R. Sasser[1], Karen L. Bierman[2], Brenda Heinrichs[2], and Robert L. Nix[3]

[1]Department of Psychiatry and Behavioral Medicine, Seattle Children's Hospital, Seattle, Washington; [2]Department of Psychology, The Pennsylvania State University; and [3]Department of Human Development and Family Studies, University of Wisconsin–Madison

Abstract

This study examined the effects of the Head Start Research-Based, Developmentally Informed (REDI) preschool intervention on growth in children's executive-function (EF) skills from preschool through third grade. Across 25 Head Start centers, each of 44 classrooms was randomly assigned either to an intervention group, which received enhanced social-emotional and language-literacy components, or to a "usual-practice" control group. Four-year-old children (N = 356; 25% African American, 17% Latino, 58% European American; 54% girls) were followed for 5 years, and EF skills were assessed annually. Latent-class growth analysis identified high, moderate, and low developmental EF trajectories. For children with low EF trajectories, the intervention improved EF scores in third grade significantly more (d = 0.58) than in the control group. Children who received the intervention also demonstrated better academic outcomes in third grade than children who did not. Poverty often delays EF development; enriching the Head Start program with an evidence-based curriculum and teaching strategies can reduce early deficits and thereby facilitate school success.

Keywords

executive function, preschool, intervention, school readiness, school adjustment, longitudinal

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Children who grow up in poverty often experience delays in executive-function (EF) development that undermine their school readiness and impede adjustment and learning after school entry (Blair & Raver, 2012; Noble, McCandliss, & Farah, 2007). Delayed EF skills mediate the association between poverty and poor academic performance, amplifying the achievement gap associated with socioeconomic disadvantage (Dilworth-Bart, 2012). Recent research demonstrates that EF skills are malleable and can be improved by preschool intervention (for a review, see Bierman & Torres, 2016). What remains unknown, however, is the degree to which efforts to improve EF skills during preschool affects growth in those skills after the transition into kindergarten. This study followed children who participated in a randomized controlled trial of the evidence-based Head Start Research-Based, Developmentally Informed (REDI) preschool intervention through third grade, examining trajectories of EF growth in early elementary school and the impact of intervention.

Development of EF

EF refers to a set of higher-order cognitive regulatory processes that underlie problem solving and goal-directed action (Blair & Raver, 2012). EF is multifaceted,

Corresponding Author:
Tyler R. Sasser, Seattle Children's Hospital, 4800 Sand Point Way NE, OA.5.134, Seattle, WA 98105
E-mail: tyler.sasser@seattlechildrens.org

reflecting (a) inhibitory control, the ability to inhibit a prepotent response in favor a more appropriate response; (b) working memory, the ability to hold and manipulate information in the mind; and (c) attention shifting, the ability to shift from one mental operation to another (Hughes, Ensor, Wilson, & Graham, 2010). These interdependent processes typically load on a single factor in early and middle childhood and are treated as a unitary construct (Wiebe, Espy, & Charak, 2008; Willoughby, Blair, Wirth, & Greenberg, 2010). EF is often described as having top-down regulatory functions that modulate bottom-up automatic responses to environmental stimuli in the attention, emotion, and stress-response systems, which thereby promotes effortful engagement in the school context (Blair & Raver, 2012).

EF development occurs over a protracted period, which makes it particularly sensitive to the quality of the external environment (Raver, McCoy, Lowenstein, & Pess, 2013). The adverse environmental conditions associated with poverty, including chaotic living conditions, exposure to violence, and insensitive caregiving, impede EF development (Bernier, Carlson, & Whipple, 2010). At the same time, emerging research suggests that early EF development may be promoted by certain kinds of enriched preschool experiences (Bierman & Torres, 2016).

One intervention approach has been to train EF skills directly by having children practice computer-based tasks. This approach has yielded disappointing results, often producing mixed findings on the trained EF skills and typically failing to show generalized impact (Melby-Lervåg & Hulme, 2013). As an alternative, enhancing preschool learning activities and improving the quality of teacher-student interactions has led to improved EF in several randomized controlled trials. For example, the Chicago School Readiness Project intervention trained teachers in positive classroom-management skills and yielded significant gains in children's EF skills. Investigators speculated that improved classroom order enhanced opportunities for engaged learning, planning, and problem solving (Morris et al., 2013; Raver et al., 2011).

Head Start REDI, the intervention featured in this study, focused on promoting social-emotional learning in preschool with the preschool Promoting Alternative Thinking Strategies (PATHS) curriculum (Domitrovich, Cortes, & Greenberg, 2007). In the logic model guiding the REDI intervention design, it was anticipated that children exposed to heightened adversities associated with poverty might benefit especially from an intensive focus on social-emotional skill building in preschool (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008). In particular, teaching children how to identify and manage strong feelings, how to employ self-regulation strategies, and how to solve problems was expected to improve their behavioral and emotion regulation and thereby foster engaged learning and development of EF skills (see also Riggs, Greenberg, Kusche, & Pentz, 2006). The REDI intervention also included an interactive reading program and sequenced learning activities to improve children's emergent literacy, language, and verbal-reasoning skills in order to further boost their self-regulation capacities and learning engagement (Lonigan, 2006). Finally, REDI staff worked with classroom teachers to establish classroom order and increase positive support for the exertion of the effortful control of emotion and behavior (Greenberg, 2006).

Indeed, postintervention assessments at the end of the preschool year revealed significant effects of the REDI intervention on an observation measure that assessed EF and a marginally significant effect on the Dimensional Change Card Sort, an EF task that taps attention-shifting skills (Bierman et al., 2008). Moderated intervention effects on academic and social-emotional outcomes were also observed, as children with lower levels of initial EF benefited most from the intervention, which suggests that the intervention's impact may be greatest for children with low EF.

Tominey and McClelland (2011) found similar moderated intervention effects: Children with the lowest EF skills benefitted the most from their preschool intervention, which involved group games designed to engage EF skills. Children with low EF skills have the most room for growth. In addition, whereas children with adequate EF skills may learn up to their potential in "usual-practice" preschool contexts, children with low EF skills may require the extra intervention support to engage actively in the classroom and experience the kinds of focused and effortful learning that improves skill development.

To date, preschool interventions have shown some positive effects on EF at the end of the intervention year, when children were still in preschool. The hope is that these early gains will set children on a better developmental trajectory after they enter school, putting low-income children on a more even playing field and allowing them to benefit from mainstream education. However, no studies have examined the degree to which preschool interventions have a sustained effect on EF development or whether the level of children's EF skills moderates the sustained impact of the intervention. The present study addressed this gap in the literature.

The Present Study

Recent research has highlighted the utility of latent-class growth analyses for detecting intervention effects in longitudinal data, particularly when those effects are limited to subgroups within the population (Lanza & Rhoades, 2013; Petras et al., 2008). The use of latent-class growth models in the present study facilitated the identification of subgroups in the sample characterized by different developmental trajectories of EF from preschool through third grade. Using these models, we aimed to assess the sustained impact of the REDI intervention on growth in children's EF skills, testing the hypothesis that intervention benefits would be amplified in the subgroup of children with low levels of EF skills (Bierman et al., 2008; Tominey & McClelland, 2011).

Method

Participants

Participants were 356 children (17% Hispanic, 25% African American, 58% European American; 54% girls, 46% boys) followed longitudinally from preschool through third grade. At the start of the study, children were 4 to 5 years old (mean age = 4.59 years, $SD = 0.32$). Participants were all from low-income families, in which the average income-to-needs ratio was .88. Forty percent of participants' parents were single. Parental education levels varied, from less than a high school diploma (33%) to a high school diploma or equivalent degree (65%) to some college (2%).

Over the course of 2 successive years, letters were sent to parents of all preschool children in 44 classrooms in 25 Head Start centers in Pennsylvania who were eligible for kindergarten the following year, and 86% agreed to participate in the study. Centers were stratified according to geographic location (rural vs. urban), full-day versus part-day attendance, and percentage of underrepresented minority students. Each center was randomly assigned to provide the intervention ($n = 192$) or the "usual-practice" control curriculum ($n = 164$). The control curriculum consisted of standard Head Start practices. After the intervention year, children were followed longitudinally as they transitioned into 202 kindergarten classrooms and subsequently into 121 first-grade classrooms, 122 second-grade classrooms, and 116 third-grade classrooms.

Retention rates across the study were high, with at least some data on EF outcomes collected for 94% of the original sample at the end of preschool, 94% at kindergarten, 92% at first grade, 87% at second grade, and 83% at third grade. Complete data were available for about 80% of the children in the sample. Data were unavailable for only 3% of the sample after the initial collection period. Overall, EF data were more likely to be missing for children in the intervention group than for children in the control group. Within the intervention group, however, there were no preintervention differences between children who did or did not have missing EF data. Within the control group, children with missing EF data were more likely to be African American and have less favorable preintervention scores on teacher-rated aggression, hyperactivity, social competence, and student-teacher relationships. Analytic models used full-information maximum-likelihood estimation to reduce any bias associated with this missing data.

Procedure

Parents provided family information, and teachers rated children's attention and behavioral functioning at the beginning of the study. Children were assessed at the beginning (preintervention) and end (postintervention) of the preschool year, as well as at the end of each subsequent year, kindergarten through third grade. At each assessment wave, trained examiners directly assessed the EF skills of children during individual test sessions at school. Teachers also rated children's academic functioning at the end of third grade. American Psychological Association ethical standards for the conduct of research were followed in this study, all parents and teachers provided informed consent for their participation, and all procedures were approved by the Pennsylvania State University Institutional Review Board.

Head Start REDI intervention

The REDI intervention lasted for 1 academic year and contained four evidence-based components targeting social-emotional functioning and language-emergent literacy skills. The REDI program also provided teachers with extensive professional-development support. To strengthen children's social-emotional skills, the REDI program implemented the preschool PATHS curriculum (Domitrovich et al., 2007), which promotes social competencies (e.g., prosocial behavior, being a good friend), emotion regulation (e.g., recognizing emotions in oneself and others), and control of aggressive impulses (e.g., self-calming and conflict-resolution skills). Teachers taught a PATHS lesson each week and completed a PATHS extension activity. In these sessions, teachers used puppets, stories, role-playing sessions, and activities to introduce social-emotional skill concepts and then encouraged children to practice and use these skills throughout the day. To improve language and emergent literacy skills, the REDI program included daily dialogic reading (Wasik, Bond, & Hindman, 2006), in which teachers used scripted questions and toy props to engage children actively in oral-reading sessions designed to improve understanding of narrative, grammatical syntax, and vocabulary. The intervention also included brief sound games (10–15 min) taught three times per week to strengthen phonological awareness (Adams, Foorman, Lundberg, & Beeler, 1998) and daily alphabet centers, in which children could see, manipulate, and memorize individual letters to support letter knowledge (Lonigan, 2006). Across all components, lessons were organized sequentially so that easier skills were presented early in the year and later lessons built on and extended these skills.

To ensure implementation quality and fidelity, the REDI program provided 4 days of in-service workshops delivered by certified program trainers and weekly coaching delivered by master teachers hired in each county and supervised by REDI personnel. Professional-development support included instruction on new lessons as well as mentoring in positive classroom-management practices, emotion coaching, and language use. REDI staff members spent an average of 3 hr per week in the classroom and 1 hr per week meeting with teachers.

Assessments of implementation quality documented moderate to strong fidelity with the REDI program's intervention procedures. Teachers reported completing 87% of daily dialogic reading activities, 86% of sound games, 84% of alphabet-center activities, and 88% of preschool PATHS lessons. REDI staff members made monthly ratings of implementation quality and fidelity, which ranged between 4.39 and 4.70 out of 5, on average, across intervention components. Observations by research staff members blind to study condition documented moderate to large differences between the intervention and control groups in the quality of teacher language use and classroom-management practices, including maintaining a supportive emotional climate and positive discipline.

Measures

EF skills. The core components of EF (working memory, inhibitory control, attention shifting) were assessed at each wave, although some measurement adjustments were made over time to accommodate developing EF skills from preschool through middle childhood. To assess working memory, we administered a Backward Word Span test (Davis & Pratt, 1995) from preschool through second grade. Children heard a list of words and were asked to repeat the list in backward order. Difficulty progressed from two to five words; the score was the total number of words the child repeated correctly. In third grade, this measure was replaced with Backward Digit Span from the fourth edition of the Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2003), which required children to repeat numbers in backward order, starting with two numbers and increasing to eight numbers.

To assess inhibitory control, we administered Walk-a-Line Slowly (Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996) at each assessment wave. Children were asked to walk along a piece of string taped to the floor as the examiner timed them. They repeated the task twice, first walking more slowly and then walking as slowly as possible. A score was calculated by subtracting the child's time on the third trial from his or her time on the first trial.

To assess attention shifting, the instructors administered the standard Dimensional Change Card Sort task (Frye, Zelazo, & Palfai, 1995; Zelazo, 2006) in preschool and kindergarten. Children sorted cards that varied along dimensions of color and shape. After learning to sort the cards by one dimension, children were asked to sort by the other dimension. The score was the percentage of postswitch trials on which cards were correctly sorted. A second measure of attention shifting, the number Stroop task (Bull & Scerif, 2001), was administered in first, second, and third grade. First, children identified number quantities when they matched the printed numerals. Then, they identified number quantities that did not match the printed numerals. The average time to complete the latter, incongruent trials was used in analyses.

Because of nonnormality in the distributions of these EF variables, raw scores were transformed (using a Box-Cox transformation) and standardized. Scores greater than 3 standard deviations from the mean were truncated to that value. The three tasks were then averaged together at each of the six points of time and restandardized to assist with interpretation of the findings. As shown in Table 1, the EF composite scores revealed a good range, skew, and kurtosis within normal limits. Alphas representing the interrelations among the EF variables in each composite were only moderate in value but were comparable with those found in other studies examining EF tasks in this age group (Bull, Espy, Wiebe, Sheffield, & Nelson, 2011).

Family and child characteristics. A series of additional measures was collected at the start of preschool and examined as predictive correlates of EF trajectories. These included two measures serving as proxies for IQ—the Expressive One-Word Picture Vocabulary Test (Brownell, 2000), which required children to give words that best described each of a series of pictures they were shown (α = .94), and the Block Design subtest from the third edition of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-III; Wechsler, 2002), which required children to use multicolored blocks to reproduce

Table 1. Descriptive Statistics for the Executive-Function Composite Measures at Each Assessment Wave

Wave	Minimum score	Maximum score	Skewness	Kurtosis	α
Preschool–fall	–2.05	3.33	.81	0.23	.44
Preschool–spring	–1.97	2.72	.24	–0.60	.47
Kindergarten	–2.78	2.47	–.43	0.22	.45
Grade 1	–2.80	3.08	–.05	0.21	.41
Grade 2	–3.51	3.22	–.26	0.78	.51
Grade 3	–3.78	3.61	–.22	1.32	.56

two-dimensional patterns. Preschool teachers completed the ADHD) Rating Scale (DuPaul, 1991) using 4-point scales (from 0, *not at all*, to 3, *very much*) to describe symptoms of inattention (e.g., "Is easily distracted"; α = .94) and impulsivity (e.g., "Has trouble waiting for his or her turn"; α = .95); symptoms were based on criteria from the fourth edition of the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-IV*; American Psychological Association, 1994). Preschool teachers also completed the Social Competence Scale (Conduct Problems Prevention Research Group, 1995) using a 6-point scale (from 1, *almost never*, to 6, *almost always*) to assess children's social-emotional skills (e.g., shares with others; α = .94). Teachers also completed the revised version of the Teacher Observation of Child Adaptation measure (Werthamer-Larsson, Kellam, & Wheeler, 1991) using a 6-point scale (from 1, *almost never*, to 6, *almost always*) to assess overt aggression (e.g., fights with other children). In all cases, when lead and assistant teachers provided independent ratings, they were averaged.

Third-grade academic outcomes. Another series of measures was collected during third grade. Reading fluency was directly assessed with the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999), which gave children 45 s to read as many short words and then as many phonetic nonwords as they could (α = .85). In each case, their score was the number correctly answered within the time limit. In addition, teachers rated children's academic performance on the language arts and mathematics subscales of the Academic Competence Evaluation Scales (ACES; DiPerna & Elliott, 2000). The language-arts subscale contained 11 items describing different facets of children's reading decoding and comprehension skills, as well as the quality of their written work (α = .97). The mathematics subscale included 8 items rating different aspects of children's mathematics skills (e.g., computation, measurement, mental math; α = .97). Items on each subscale were rated on a 5-point scale from *far below* to *far above* grade-level expectations and then averaged to create a total subscale score.

Children also provided self-evaluations of their reading ability using the six-item Perceptions of Difficulty with Reading subscale from the Reading Self-Concept Scale (Chapman & Tunmer, 1999), which describes perceptions of difficulties children experience while reading (e.g., "Do the other kids in your class read better than you?" "Do you make lots of mistakes in reading?"). Items were rated on a 4-point scale (1, *almost never*, to 4, *almost always*), summed (α = .80), and reverse-scored so that high scores represented more positive self-evaluations. Finally, teachers completed the Child Development Questionnaire created for this study and 12 yes/no items to describe the child's need for and use of any special education or adjunct support services at school, including an individualized education program, speech and language services, learning support, and behavioral support (α = .83). Items were totaled to reflect the total number of services needed and used. All third-grade outcome variables were standardized (M = 0, SD = 1) within the sample.

Plan of analysis

Analyses for this study proceeded in three stages. First, latent-class growth analysis (Nagin, 2005) was conducted using the whole sample to identify trajectories of EF development from preschool through third grade. Posterior probabilities were used to assign children to trajectory classes, and chi-square tests or analysis of variance (ANOVA) explored the child and family characteristics that significantly predicted placement in those EF-trajectory classes. Second, intervention effects were examined by adding intervention status to the growth models. Initially, intervention effects were assessed using a one-class model to determine whether there was a main effect of intervention on the whole sample. Intervention status was then examined in the multiclass model to determine the impact of the intervention on the slope and third-grade intercept of EF within the different EF-trajectory classes. Finally, in the third stage of analyses, intervention effects were

Table 2. Correlations Between Executive-Function Composite Measures Over Time

Wave	Preschool–spring	Kindergarten	Grade 1	Grade 2	Grade 3
Preschool–fall	.56	.41	.37	.39	.36
Preschool–spring	—	.45	.49	.49	.45
Kindergarten		—	.52	.55	.51
Grade 1			—	.64	.64
Grade 2				—	.72

Note: All correlations are statistically significant ($p < .01$).

examined on the third-grade academic outcomes of children within each EF-trajectory class.

Results

Prior to running latent-class analyses, we computed simple correlations to evaluate the stability of the EF composites over the six waves of data collection (see Table 2). This analysis revealed moderate stability over time.

Developmental trajectories of EF

In the first stage of data analyses, latent-class growth analysis was used to identify the number of underlying groups represented in the EF composite variable; models with two to five developmental-trajectory classes were estimated (see Table 3). Although Bayesian information criteria and Akaike's information criteria continued to improve after three groups had been identified, the four- and five-class model solutions added very small classes that split off children with extreme values. For example, the four-class solution created a very small class of 18 children with extremely high EF scores (averaging more than 1.5 *SD* above the sample mean), and the five-class solution decreased the size of the lowest trajectory group to 10 subjects, of which only 3 were included in the intervention. Given a goal of this study to understand the possible differential benefits of intervention for children showing different developmental trajectories of EF, these very extreme classes were deemed too small to provide interpretable information. For this reason, the three-class solution was selected as optimal.

The resulting trajectory classes are shown in Figure 1. The high-EF group, which comprised 16% of the entire sample, was persistently around 1 standard deviation above the sample EF mean and was stable over time, with no statistically significant linear or quadratic slope. The moderate-EF group was larger, comprising 58% of the sample. This group was always around the sample mean and showed a slight but steady increase over time, with a significant positive linear slope but no significant quadratic slope. The low-EF group was smallest, comprising 26% of the sample. This group scored persistently around 1 standard deviation below the sample mean and had a significant linear slope that decreased from preschool to third grade. Posterior probabilities were high across the classes, which suggests strong membership classification (see Table 3).

Family and child characteristics associated with EF trajectories

To identify family demographic and child characteristics that predicted placement in different EF-trajectory classes, we used chi-square tests for categorical variables and ANOVAs for interval variables to compare the initial

Table 3. Parameters of the Candidate Latent-Class Growth Models

Number of classes	Bayesian information criterion	Akaike's information criterion	Range of posterior probabilities	Size of smallest class
Two	–2,543	–2,547	.92–.93	47%
Three	–2,469	–2,477	.89–.93	16%
Four	–2,434	–2,445	.89–.91	5%
Five	–2,419	–2,432	.82–.98	4%

Note: The model with three developmental-trajectory classes was selected as the optimal model.

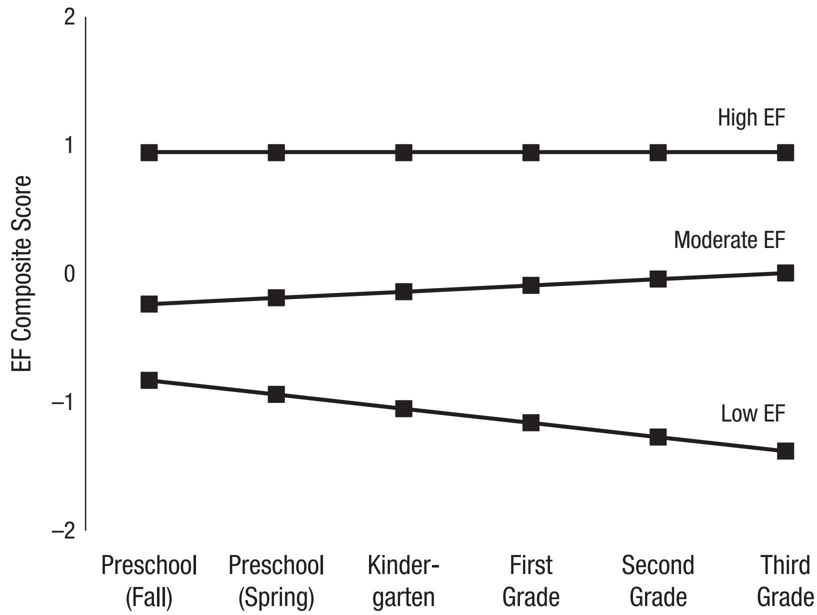

Fig. 1. Mean executive-function (EF) composite score for children at each of the six assessment waves, separately for groups with high, moderate, and low EF trajectories.

preschool scores of children who subsequently followed different EF trajectories. Chi-square tests revealed no significant differences across EF-trajectory classes in the proportion of females, $\chi^2(2, N = 365) = 1.47$, $p > .250$; African American children, $\chi^2(2, N = 365) = 1.85$, $p > .250$; Latino children, $\chi^2(2, N = 365) = 0.49$, $p > .250$; children from single-parent families, $\chi^2(2, N = 365) = 2.84$, $p = .240$; or, notably, children from the intervention versus control groups, $\chi^2(2, N = 365) = 1.26$, $p > .250$.

However, as shown in Table 4, children with high EF trajectories came from families of higher socioeconomic status and were older than children with moderate and low EF trajectories. Measures of child preschool competencies also predicted trajectory class, with significant differences emerging between each class on proxy measures of IQ (i.e., Expressive One-Word Picture Vocabulary Test and Block Design), inattention, and social competence. Children with high EF trajectories had significantly more favorable scores than children with moderate EF trajectories, who in turn had significantly more favorable scores than children with low EF trajectories. In addition, teachers rated children with low EF trajectories as more impulsive and aggressive than children with high or moderate EF trajectories.

Table 4. Comparison of the Characteristics of the Three Executive-Function (EF) Trajectories

	EF trajectory				
Characteristic	High	Moderate	Low	$F(2, 352)$	p
Family SES	25.41_a	21.16_b	19.70_b	7.43	< .001
Child age (years)	4.58_a	4.50_a	4.28_b	16.77	< .001
EOWPVT score	42.11_a	34.13_b	25.08_c	50.02	< .001
Block Design score (WPPSI-III)	21.13_a	19.43_b	16.06_c	38.47	< .001
Inattention	0.57_a	0.78_b	1.26_c	17.46	< .001
Impulsivity	0.68_a	0.77_a	0.99_b	3.19	.042
Social competence	4.27_a	4.01_b	3.50_c	14.18	< .001
Aggression	1.87_a	1.88_a	2.20_b	3.01	.050

Note: For each EF trajectory class, the table presents means. Within a row, means with different subscripts are significantly different ($p < .05$, based on Duncan post hoc comparisons). Socioeconomic status (SES) was measured according to the Hollingshead (1975) index; EOWPVT = Expressive One-Word Picture Vocabulary Test (Brownell, 2000); WPPSI-III = Wechsler Preschool and Primary Scale of Intelligence–Third Edition (Wechsler, 2002).

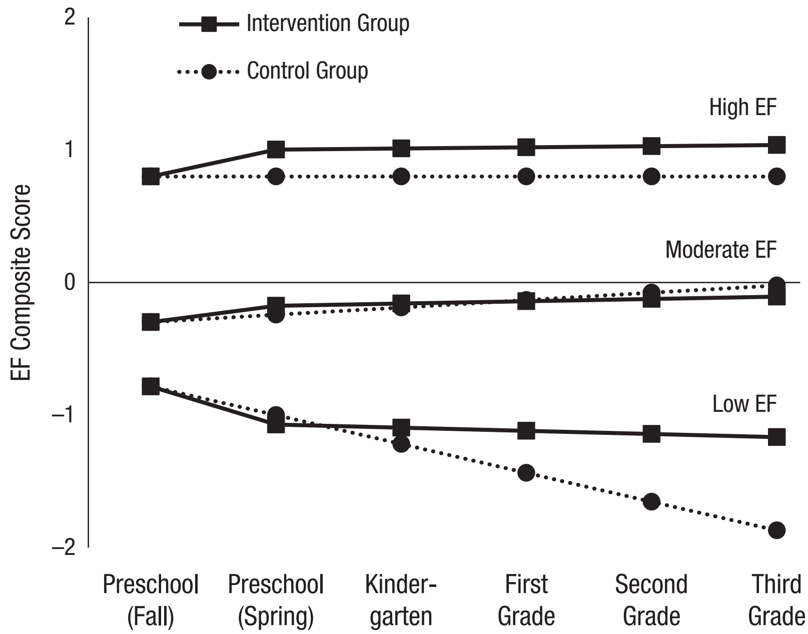

Fig. 2. Mean executive-function (EF) composite score for children in the intervention and control groups at each of the six assessment waves. Results are shown separately for groups with high, moderate, and low EF trajectories.

Effects of the intervention within EF trajectories

To determine whether there was an effect of the REDI intervention within each EF-trajectory class, we included the categorical variable indicating intervention status in the latent-class growth model, starting at the spring preschool semester, with child age added as a covariate. Initially, a one-class model was run to estimate the impact of the intervention on the third-grade intercept and slope of EF for children within the whole sample. No significant intervention effects emerged for this model (ps > .250). Then, intervention was included in the model with three EF classes. This model estimated the impact of intervention on the third-grade intercept and the slope of EF for children within each trajectory class, thereby testing for intervention effects moderated by EF class. Model-derived estimates of EF at each assessment for children in the intervention and control groups within each class are presented in Figure 2. A significant effect of intervention emerged for children with low EF trajectories, with children in the intervention group showing a more positive slope of growth in EF between preschool and third grade (d = 0.19, p = .004) and exhibiting significantly higher third-grade EF scores (d = 0.70, p = .002), compared with children in the control group. In addition, among children with high EF trajectories, those in the intervention group exhibited higher third-grade EF scores than those in the control group (d = 0.24, p < .035), although there was no significant intervention effect on the slope of EF growth within this trajectory class. No significant intervention effects on third-grade EF scores or growth slope emerged for children with moderate EF trajectories (ps > .250).

Intervention effects on third-grade academic outcomes within EF trajectories

The last set of analyses was conducted to determine whether moderated intervention effects emerged on third-grade academic outcomes, consistent with the intervention effects on EF. In these analyses, one-way ANOVAs compared the academic outcomes of children in the intervention and control groups within each of the EF trajectories. Demographic variables (sex, race, age, county site) and preintervention cognitive skills (vocabulary, Block Design, emotion-recognition skills, and EF) were covariates. As shown in Table 5, significant intervention effects favoring children in the intervention group emerged for children with low EF trajectories on a direct assessment of reading fluency (TOWRE), teacher ratings of language arts and math performance (ACES), and children's self-perceptions of their reading ability. For children with low EF trajectories, there was also a nonsignificant trend suggesting a

Table 5. Third-Grade Academic Outcomes for the Intervention and Control Groups Within Each Executive-Function (EF) Trajectory

Academic outcome	Low EF trajectory		Moderate EF trajectory		High EF trajectory	
	Intervention	Control	Intervention	Control	Intervention	Control
Reading Fluency (TOWRE)	–0.58 (0.21)	–1.30 (0.24)	0.04 (0.10)	0.09 (0.10)	0.50 (0.16)	0.37 (0.18)
Language Arts (ACES)	–0.35 (0.20)	–1.04 (0.22)	0.10 (0.09)	0.03 (0.10)	0.54 (0.16)	0.43 (0.17)
Math (ACES)	–0.45 (0.19)	–1.00 (0.22)	0.03 (0.09)	0.04 (0.09)	0.50 (0.15)	0.39 (0.17)
Self-perceptions of reading ability	–0.21 (0.23)	–1.06 (0.27)	–0.14 (0.11)	0.14 (0.11)	0.54 (0.16)	0.43 (0.17)
Need for special school services	.30 (.21)	.84 (.24)	.01 (.10)	.17 (.10)	–.35 (.17)	–.03 (.19)

Note: The table presents standardized scores; standard errors are shown in parentheses. For the low-EF-trajectory class, the difference between means for the two groups was significant ($p < .05$) for all outcomes except the need for special services, for which the difference was marginally significant ($p < .10$). TOWRE = Test of Word Reading Efficiency (Torgesen, Wagner, & Rashotte, 1999); ACES = Academic Competence Evaluation Scales (DiPerna & Elliott, 2000).

need for fewer special school services. No intervention effects emerged on these academic outcomes for children with moderate or high EF trajectories, although means tended to favor children who received the REDI intervention.

Discussion

The REDI intervention delivered during preschool had sustained benefits for children with low EF trajectories. Compared with their counterparts who received the "usual-practice" Head Start curriculum, children with low EF skills who received the REDI intervention during Head Start showed more favorable development over time, as well as significantly higher levels of EF at third grade—by more than two-thirds of a standard deviation. Furthermore, among children with low EF trajectories, those who received the intervention outperformed the control group on all third-grade academic outcomes examined. These findings extend the EF benefits documented at the end of the intervention (Bierman et al., 2008), which makes this the first study to demonstrate that preschool interventions can affect EF development into middle childhood for children with low EF levels and that EF levels moderate the effect of intervention on academic functioning.

Children with low EF developmental trajectories were younger, had lower verbal and nonverbal IQ scores, poorer attention skills, and less social-emotional competence when they entered preschool than did children in the other trajectory classes. Children in this EF-trajectory class thus faced heightened vulnerability for school difficulties because of their less well-developed cognitive and behavioral competencies. Hence, it is particularly notable that this subgroup was most helped by the preschool intervention both in terms of EF and academic functioning.

Although family history for children in the low-EF class was not available, it is possible that these children were exposed to heightened levels of stress, low levels of stability, less sensitive caregiving, and little cognitive stimulation in their early years, which may have contributed to the delays in their preschool EF skills (Blair & Raver, 2012). As such, the social-emotional curriculum and strategies used in intervention classrooms to provide structure and support may have been particularly helpful to these children, along with the explicit instruction and role-play opportunities the intervention included to foster emotional understanding, self-regulation, and problem-solving skills. The interactive reading program that focused on social-emotional themes, combined with enriched language use in the classroom, may also have boosted intervention benefits for these children.

Without the REDI intervention, control-group children with low EF trajectories showed a declining EF slope after kindergarten entry, which indicates that they were falling further behind children in the other trajectories in EF-skill development during the early elementary years. The REDI intervention fostered resilience, preventing this decline. Previously published follow-up studies document sustained effects of the REDI intervention on children's learning behaviors and social competence through third grade (Bierman, Heinrichs, Welsh, Nix, & Gest, 2017; Nix et al., 2016). It may be that by enhancing children's learning and social behaviors, the

REDI intervention increased the quality of child engagement in elementary school classrooms, which thereby provided more opportunities for children with low EF trajectories to utilize and practice applying EF skills. Improved classroom engagement may protect children with low EF levels from declines in the pace of cognitive growth.

An interesting, albeit unexpected, finding in this study is that among children with high EF levels, those in the intervention group showed higher levels of EF at third grade compared with those in the control group, but the two groups did not differ in rate of change. One hypothesis for this somewhat surprising result is that intervention children with high EF were well-regulated (cognitively and behaviorally) and thus suited to take advantage of the enriched instructional content provided in REDI classrooms. For children with high EF trajectories, the benefit of the intervention was observed during the preschool year and then sustained over time, showing a different pattern than the evolving benefits experienced by children with low EF trajectories.

The current study did not find any intervention effects for children with moderate EF trajectories. Perhaps these children did not require the remedial support provided by the social-emotional components of the REDI intervention that may have benefited children with low EF trajectories, nor were they particularly primed to benefit from the enriched instructional content in REDI classrooms.

A key limitation of this study is that it is not possible to determine the specific aspects of the intervention or mechanisms of action that accounted for the sustained benefits for children with low EF skills, and so these interpretations of the findings remain speculative. One cannot determine the degree to which either the components of the intervention curriculum or teachers' professional-development support contributed to child outcomes, and the study did not include an active control group for the extra attention and support teachers received. In addition, latent-class growth models are affected by sample-specific variance; additional studies are needed to validate the developmental trajectories of EF found in this study. Finally, the use of an EF composite, while common practice for younger children, does not provide information about the specific nature of the impact of the intervention.

Conclusions

Interest in children's EF skills has increased over the past 20 years, along with hope that promoting early EF-skill development can enhance the outcomes of children growing up in poverty. The current study validates the potential of enriching preschool interventions in ways that improve EF skills and have sustained benefits during elementary school for the subgroup of children at particular risk for school difficulties. These findings suggest that evidence-based social-emotional programming and enriched language use in preschool classrooms may be particularly valuable for promoting later classroom engagement and EF growth during elementary school. However, additional research is needed to identify the key preschool elements and mechanisms of action associated with sustained intervention benefits.

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Author Contributions

T. R. Sasser developed the study concept. All the authors contributed to the study design. K. L. Bierman and R. L. Nix oversaw measure selection and data collection. B. Heinrichs analyzed the data. T. R. Sasser drafted the manuscript, and the other authors provided critical revisions. All the authors approved the final version of the manuscript for submission.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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