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THE SUSTAINED IMPACT OF THE HEAD START REDI INTERVENTION ON CHILDREN'S EXECUTIVE FUNCTION TRAJECTORIES THROUGH THIRD GRADE

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Abstract

This study examined the sustained effects of the Head Start REDI (Research-based, Developmentally-Informed) intervention, a randomized controlled preschool preventive intervention, on growth in children's executive function (EF) skills from preschool through middle childhood. Forty-four classrooms were randomly assigned to receive Head Start REDI, which employed enhanced social-emotional and language/emergent literacy curriculum and strategies, or "usual practice" Head Start. The 356 4-year-old children (25% Aftrican American; 17% Latino; 54% girls) in those classrooms were followed for five years into third grade. Children's EF skills were assessed annually. Two approaches were used to examine the sustained impact of REDI on growth in EF: latent growth curve modeling and latent class growth analysis. Results of latent growth curve modeling demonstrated the normative developmental process of EF over time, but did not find main or interaction (by initial EF status) effects of the intervention beyond normative development. Latent class growth analysis identified three EF trajectory classes at approximately high, moderate, and low levels of EF over time. Tests revealed significant intervention effects within the high and low trajectory classes, suggesting that of the children with high and low EF, those who were in REDI classrooms had significantly better EF outcomes than those who were not. This is the first study to document that preschool preventive interventions can have lasting impacts on EF growth in low-income children. These findings demonstrate how enriching Head Start with evidence-based curriculum and strategies can foster EF skill development, which is critical for children's broader academic and social-emotional success.

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Introduction

Over the past 20 years, there has been considerable interest in executive function (EF) as it relates to children's school success. In part, this interest has emerged due to the possibility that delays in EF development explain some of the negative effect that poverty has on children's school readiness and subsequent achievement and attainment (Blair, 2002). Rates of child poverty are on the rise in the United States, now affecting one of four preschool-aged children, and one of five children overall (Children's Defense Fund, 2014). Developmental differences between disadvantaged children and their advantaged peers are apparent in the first few years of life (Ryan, Fauth, & Brooks-Gunn, 2005). By school entry, disadvantaged children exhibit poorer language and emergent literacy skills (Zill et al., 2003), and by childhood they perform significantly worse on tests of achievement (Ryan et al. 2005). Ultimately, growing up in poverty has been linked with a range of adverse outcomes in adulthood (Jackson et al., 2004), increasing the likelihood of intergenerational poverty (Children's Defense Fund, 2014).

It is also well established that poverty is linked with delays in the development of the prefrontal cortex (PFC) of the brain, as well as an associated set of higher-order cognitive regulatory processes called EF, which are responsible for planning, problem-solving, and rule-governed behavior (Farah et al., 2006; Noble, McCandliss, & Farah, 2007; Raver, Blair, Willoughby, & the Family Life Project Key (FLP) Investigators, 2013; Raver, McCoy, Lowenstein, & Pess, 2013). Delays in EF in early and middle childhood have been linked to poorer academic skills and social competence (Allan & Lonigan, 2011; Bierman, Torres, Domitrovich, Welsh, & Gest, 2009; Blair & Razza, 2007; Sasser, Bierman, & Heinrichs, 2014; Welsh, Nix, Blair, Bierman, & Nelson, 2010), as well as developmental disorders and psychopathologies (Pennington & Ozonoff, 1996). It is believed that environmental influences associated with poverty impact the development of the PFC and, consequently, EF abilities, and that compromised EF impairs the growth of key academic, social, and behavioral capacities in childhood and beyond (Blair, 2002). Consistently across longitudinal studies, EF skills mediate the association between poverty and early academic skill delays (Dilworth-Bart, 2012; Fitzpatrick, McKinnon, Blair, & Willoughby, 2014; Nesbitt, Baker-Ward, & Willoughby, 2013). In recent years, research on the development of EF has proliferated, spurred especially by the hope that understanding and facilitating this set of cognitive control capacities might enhance school readiness and achievement among children growing up in poverty (Hughes, 2011; Raver, Blair et al., 2013).

Importantly, emerging research suggests that the pace of early EF development may be malleable, and the delays associated with poverty may be off-set to some degree by providing low-income children with certain kinds of enriched preschool experiences (Bierman & Torres, in press; Blair & Raver, 2012b). In particular, several preschool interventions that target the nature and quality of teacher-student interactions have led to improvements in EF scores (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Diamond, Barnett, Thomas, & Munro, 2007; Raver et al., 2011; Tominey & McClelland, 2011). To date, these classroom interventions have studied the impact on EF in a time-limited way, by testing for intervention-control group differences at the end of the preschool year.

Many questions remain regarding EF, and the proposed study aims to address the following gaps in the literature utilizing data from the Head Start REDI intervention project. First, most studies have examined EF growth longitudinally during either the preschool period or adolescence. This study expands upon existing research by focusing on EF growth from the preschool years through middle childhood. Second, although research suggests that specific kinds of high quality preschool interventions can boost the EF abilities of disadvantaged children, no studies have examined the longer-term effects of intervention on growth in children's EF. This study expands upon this research by examining the impact of a pre-kindergarten intervention on EF growth through third grade.

Executive Function

EF refers to a set of higher-order cognitive regulatory processes that underlie complex human behaviors such as planning, problem-solving, and goal-directed action (Blair, 2002). EF is often considered a multifaceted construct, reflecting: (1) inhibitory control, the ability to inhibit a prepotent response in favor a more appropriate response, (2) working memory, the ability to hold and manipulate information in mind, and (3) attention shifting, the ability to flexibly shift from one mental operation to another (Hughes, 2011; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Research suggests that inhibitory control, working memory, and attention shifting represent inter-dependent processes that facilitate adaptive problem-solving in novel situations; they typically load on a single factor and are treated as a unitary construct in the early and middle childhood period (Hughes, Ensor, Wilson, & Graham, 2010; Wiebe, Espy, & Charak, 2008; Willoughby, Blair, Wirth, Greenberg, & the FLP Investigators, 2010). The interdependence among these facets of EF appears to stem in large part from their shared reliance on the PFC (Bernstein & Waber, 2007).

Executive Function and School Success

EF is considered an important aspect of children's self-regulation, which is itself a multi-faceted domain referring to children's capacity to control their attention, thoughts, emotions, and actions (Derryberry & Rothbart, 1988). In particular, EF has been placed in models of self-regulation as a "top-down" regulatory component involved in the volitional control of "bottom-up" or automatic responses to environmental stimuli in the attention, emotion, and stress response systems (Blair, 2002; Blair & Ursache, 2011; Miller & Cohen, 2001). This "top down" control promotes effortful engagement in novel and complex learning tasks, enables children to initiate and coordinate their behavior in response to social expectations and norms, and fosters the inhibition of aggressive impulses (Raver, Blair et al., 2013; Miller & Cohen, 2001).

Numerous recent studies have established the link between EF and school success. Considerable evidence suggests that EF is a positive predictor of concurrent and future reading and math achievement (Allan & Lonigan, 2011; Blair & Razza, 2007; Bull, Espy, Weibe, Sheffield, & Nelson, 2011; Bull, Espy, & Wiebe, 2008; Clark, Pritchard, & Woodward, 2010; Dilworth-Bart, 2012; Lan, Legare, Ponitz, Li, & Morrison, 2011). This pattern of associations, however, tends to be stronger for math achievement than for reading (Blair & Razza, 2007; Bull et al., 2008; Sasser et al., 2014). Evidence also suggests that EF is associated with growth in achievement during the preschool and early elementary school period (Matthews, Ponitz, & Morrison, 2009; McClelland, Ponitz, & Morrison, 2007; Ponitz, McClelland, Matthews, & Morrison, 2009; Welsh et al., 2010). Concurrent links between EF skills and social-emotional adjustment have also been documented (Bierman et al., 2009). Predictive links exist between EF skills in early elementary school and social competence one year later (Ciariano, Visu-Petra, & Settanni, 2007), as well as social competence and reduced aggression two years later, controlling for baseline behaviors (Riggs, Blair, & Greenberg, 2003).

Executive Function Development

At a neurobiological level, the PFC and associated neural networks are considered to underlie EF abilities (Fuster, 1997). The PFC and, consequently, EF exhibit a prolonged period of postnatal development, undergoing maturation throughout childhood, and well into adolescence and early adulthood (e.g., Chelune & Baer, 1986; Davidson, Amso, Anderson, & Diamond, 2006; Huizinga, Dolan, & van der Molan, 2006; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Welsh, Pennington, & Groisser, 1991). Recently, there has been a surge of interest in the development of EF during the early childhood and preschool years (Hughes, 2011). Research suggests that considerable development in EF occurs in the preschool period (between the ages of 3 and 5), as evidenced in preschool children's increased ability to organize their thinking, adapt their behavior with greater flexibility, decrease their reactive responding, and engage in rule-governed activities (Diamond, 2001; Garon, Bryson, & Smith, 2008). Furthermore, studies have linked individual differences in EF growth with children's adjustment to school. For instance, in a longitudinal study, Hughes and Ensor (2011) found that individual differences in EF growth from ages 4 to 6 were negatively associated with hyperactivity and peer problems, and positively associated with self-perceived academic ability at age 6.

Although understudied, much of the development of the PFC and associated EF occurs after age 5 and, in particular, during the middle childhood period (Andersen, 2002). Yet, much of the longitudinal research on EF development has followed children in narrow age ranges, from preschool to school entry or from early to later adolescence, leaving the early to middle childhood transition rather underexplored (Best, Miller, & Jones, 2009). Cross-sectional studies have documented mean-level growth in EF skills across the childhood years (Huizinga et al., 2006; Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003), yet little is known about individual differences in growth in EF from early to middle childhood.

One of the important challenges to the examination of EF development in prospective longitudinal studies that span the transition from early to middle childhood lies in the way EF is typically measured (Best et al., 2009; Best & Miller, 2010). Despite the proliferation of age-appropriate EF tasks (Garon et al., 2008; Hughes, 2011), many of these tasks involve brief games that are challenging for children in relatively narrow age groups. For instance, the peg tapping (Diamond & Taylor, 1996) task, designed for preschoolers, requires a child to tap a pencil twice when an interviewer taps once and to tap once when the interviewer taps twice. Whereas the peg tapping task challenges preschool children with a novel problem-solving (Carlson, 2005; Diamond & Taylor, 1996), almost all children can master this task by kindergarten, limiting its capacity to assess individual differences after the transition into elementary school.

In general, the threat of floor effects on EF tasks at younger ages requires researchers to employ simple, short tasks. Unfortunately, these tasks very quickly show ceiling effects when used with older children. To cover longer developmental periods, researchers modify tasks, adopt a more complex version of a task, or remove and add tasks altogether, making it more challenging to assess developmental trajectories. Techniques such as latent growth curve modeling have recently been developed to address such adjustments while still maintaining essential measurement characteristics (e.g., Hancock & Buehl, 2008).

Poverty and Executive Function Development

The unusually protracted development of the PFC and EF render them particularly sensitive to the external environment (Bull et al., 2011; Raver, McCoy et al., 2013). In fact, some have argued that EF emerges as a result of the interaction between the developing PFC and the quality of the environment (Calkins & Fox, 2002; Diamond, 2009; Diamond et al., 2007; McCabe, Cunnington, & Brooks-Gunn, 2004). In response to environmental challenges, children react in biologically-driven ways, sometimes described as “bottom up” or automatic regulatory processes that involve the attention, emotion, and stress response systems (Blair, 2010; Blair & Raver, 2012a; Blair & Raver, 2012b; Ursache, Blair, & Raver, 2012). Under some environmental conditions, these systems are engaged at levels that allow for deployment of and growth in "top down" EF capacities across early childhood. As EF abilities are activated and used, children are increasingly able to manage attention, emotion, and stress in a positive feedback loop. However, under adverse environmental conditions, including those associated with growing up in poverty, "bottom up" reactive processes may be activated at levels that are not conducive to EF. Conceptually, exposure to chronic stressors and a lack of predictability in the environment may lead to a chronic over-activation of the stress-response systems, impeding the child's capacity to develop adaptive coping strategies and engage in effortful problem-solving (Blair, 2010). While reactive systems are designed biologically to protect individuals from immediate threat and are therefore arguably adaptive in such environments, acute or chronic activation of the automatic attention, emotion, and stress response systems may overwhelm EF and constrain its development over the long term.

As such, although development of EF is dependent upon biological maturation, exposure to adverse versus enriched environmental conditions plays a large role in shaping emerging EF. In particular, research clearly suggests that growing up in poverty negatively impacts children's developing EF skills (Blair, 2010; Bull et al., 2011; Farah et al., 2006; Noble, Norman, & Farah, 2005; Raver, Blair et al., 2013). Conceptual and empirical work suggests that exposure to impoverished living conditions increases the presence of some stress hormones and neurotransmitters, which appears to alter the neural pathways associated with EF (Blair, 2010; Kishiyama, Boyce, Jimenez, Perry, & Knight, 2009). In addition, the lack of supportive and sensitive scaffolding by trusted caregivers may impede the child's ability to acquire and practice effortful coping and problem-solving (Bernier, Carlson, Deschenes, & Matte-Gagne, 2012).

Developmental research indicates that the optimal conditions for the development of self-regulation generally, and EF specifically, are characterized by sensitive and responsive caregiving, guided exploration of the environment, sustained joint attention to activities, and the effective scaffolding of emotional understanding, planning, and problem-solving (Bernier et al., 2012). Furthermore, research suggests that more well-ordered environments may also influence the development of EF skills, as clear and consistent sequences, cues, and contingencies may promote understanding of cause-and-effect sequences and encourage the use of planning (Barkley, 2001; Bodrova & Leong, 2007).

Intervention and Executive Function Development

Although research suggests that EF skills develop rapidly across the preschool and early school years, and that children's experiences appear to affect EF skill development, not much is known about how to promote EF skills, particularly over the longer term. One intervention approach has been to "train" EF skills directly, by having children practice computer-based tasks that are similar to those used to evaluate EF. This approach has yielded disappointing results at the preschool age, often producing mixed findings on the EF skills being trained (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005) and typically failing to show any generalized impact on cognitive or behavioral functioning in the classroom (Owen et al., 2010). As an alternative, and consistent with the previously reviewed literature, it has been posited that by enhancing the school environments of children growing up in poverty in strategic ways, interventions can foster conditions that allow children to use and grow EF (Blair, 2002; Ursache et al., 2013). Consistent with this hypothesis, three recent studies suggest that specific preschool interventions can boost the EF abilities of disadvantaged children (Bierman, Nix et al., 2008; Diamond et al., 2007; Raver et al., 2011). Each of these programs made strategic efforts to improve the quality of emotional and instructional support in the classroom, and to change the nature of some classroom activities in order to accelerate EF development.

For instance, the Chicago School Readiness Project [CSRP] targeted classroom climate by providing Head Start teachers with training and coaching designed to enhance their ability to handle everyday challenges (e.g., peer conflict, teacher stress; Raver et al., 2008). CSRP used the Incredible Years teacher training program (Webster-Stratton, Reid, & Hammond, 2001) to improve classroom management, increasing positive support and contingent responding by teachers and thereby promoting student engagement in learning. CSRP also increased classroom organization by establishing predictable routines, and decreased critical corrections and negative discipline. Results from a randomized-controlled trial suggested that children in intervention classrooms had higher EF scores and lower inattention/impulsivity ratings at the end of the intervention year than children in control classrooms, and that these differences mediated the impact of the intervention on children's academic readiness for school (Raver et al., 2011).

A second preschool program, Tools of the Mind, (Bodrova & Leong, 2007) focuses on increasing teacher scaffolding for complex peer interactions that were expected to boost EF. For example, teachers are taught how to support complex socio-dramatic play in the classroom. Tools also reorganizes large group activities to provide children with more opportunities for active learning, and includes motor games and activities designed to practice self-regulation skills, such as *Simon Says.* An initial randomized-controlled trial showed that *Tools* significantly improved the quality of teaching observed in the classrooms, including positive classroom structure and quality of the literacy environment and instruction, and teachers reported fewer behavior problems (Barnett et al., 2008). Assessment a year later also showed significant effects on children's executive function skills (Diamond et al., 2007); however, these latter assessments were made after teachers and children were allowed to change programs if desired, compromising the original randomization and introducing the potential for selection biases.

The present study focuses on the third preschool program that recently demonstrated positive impact on children's EF at the end of preschool. Designed as an enrichment to existing Head Start programs, the REDI intervention adopted evidence-based program components and practices to foster children's language, emergent literacy, social-emotional, and self-regulation skills. Central to the REDI program was a focus on enhancing social-emotional support in preschool, using the Preschool PATHS (Promoting Alternative Thinking Strategies) curriculum and strategies (Domitrovich, Greenberg, Kusche, & Cortes, 2005). This curriculum targets children's emotion recognition, prosocial skills, self-regulation, and social problem-solving, and, when used alone, has been shown to boost children's social-emotional competence (Domitrovich, Cortes, & Greenberg, 2007). In the REDI program, Preschool PATHS was combined with intervention components targeting language and emergent literacy skills. For example, dialogic reading, in which teachers read interactively with students, has been shown to foster language use in Head Start classrooms and boost child vocabulary (Wasik, Bond, & Hindman, 2006; Whitehurst et al., 1994). The use of sequenced learning activities has promoted children's emergent literacy skill development (Adams, Foorman, Lundberg, & Beeler, 1998; Lonigan, 2006).

REDI was hypothesized to enhance EF primarily by promoting social-emotional learning and self-regulation using Preschool PATHS curriculum (Bierman, Domitrovich et al., 2008). This hypothesis was built upon a previous evaluation conducted with second and third grade students in which the PATHS Curriculum fostered inhibitory control skills, and that improvement in inhibitory control partially mediated the impact of PATHS on subsequent externalizing and internalizing behavior (Riggs, Greenberg, Kusche, & Pentz, 2006). In the REDI intervention project, it was anticipated that Preschool PATHS (Domitrovich et al., 2005; Domtrovich et al., 2007) would similarly promote EF by establishing classroom rules and routines, providing explicit training in friendship skills and emotion knowledge, and teaching children a strategy for emotion regulation and problem-solving. The randomized control trial of REDI included 356 preschoolers in 44 Head Start classrooms. Randomization occurred at the classroom level, such that half of the classrooms (n = 22) were enhanced with evidence-based curriculum and strategies, and the other half delivered the "usual practice" Head Start program.

At the end of the intervention year, significant intervention effects were observed on several aspects of children's academic and social-emotional school readiness (Bierman, Domitrovich et al., 2008). Additionally, significant effects were documented on two aspects of EF, a cognitive performance task (DCCS, $d \sim .20$, $p = .08$) and a behavioral performance task (task orientation, $d \sim .28$, $p < .05$), and these gains partially mediated intervention effects on children's academic and social-emotional school readiness (Bierman, Nix et al., 2008). Interestingly, moderated intervention effects were also observed. Children with lower levels of initial EF benefited more from the intervention on some outcomes, exhibiting higher levels of print awareness and social competence and lower levels of aggression.

Each of these three preschool interventions thus demonstrated positive effects on EF skills at the end of the preschool year; however, none of them reported on children's EF skills in elementary school to determine the degree to which sustained effects were evident after the school transition. A key question remaining is whether the positive impact on EF during the preschool years was sustained in later years, after children transitioned into kindergarten; this study addresses this issue with a follow-up assessment of children in the REDI trial.

Sustained Intervention Effects on EF Development

The hope of school readiness interventions is that the delivery of evidence-based strategies during the early school years will set children on a better developmental trajectory throughout childhood, adolescence, and even into adulthood. To date, few studies have been conducted to examine whether the benefits of evidence-based enhancements such as those adopted in REDI were sustained over time, and no studies have examined sustained effects on children's EF development. In REDI, a follow-up study demonstrated sustained benefits associated with the REDI intervention after children transitioned into kindergarten, including statistically significant effects on phonemic decoding (d = .27), competent social problem-solving skills (d = .38), teacher and parent ratings of reduced aggression (d = .20-.25), and teacher ratings of children's learning behaviors (d = .27; Bierman et al., 2014). These findings suggest that many of the social-emotional benefits of REDI were sustained after children transitioned into kindergarten. However, the degree to which gains in EF were sustained after the transition remains unknown.

To determine whether intervention effects have been sustained over longer periods of time, most intervention trials examine intervention-control group differences at some point after the intervention has been concluded (e.g., 6 months, 12 months). However, there have been increased arguments in favor of data analytic approaches that maximize the use of longitudinal data and provide more nuanced information regarding the impact of the intervention on developmental outcomes. For example, a recent REDI study employed a person-oriented modeling approach, latent class growth analysis, to show that children in enhanced REDI classrooms were more likely than children in control classrooms to follow the most optimal developmental trajectories of social competence, aggressive-oppositional behavior, learning engagement, attention problems, student-teach closeness, and peer rejection from preschool to third grade (Nix et al., under review). Latent class growth analysis holds promise for examining potential sustained intervention impact on EF as well.

Proposed Study

The current study employed two complementary longitudinal analytic approaches, latent growth curve modeling and latent class growth analysis, to address the following study aims. The first aim of the study was to model change in EF from preschool to middle childhood, an understudied period characterized by remarkable EF growth. It was anticipated that children's EF skills would improve across development, although no hypotheses were offered regarding the specific shape of EF development over this period. Individual differences in the levels and rates of change in EF were expected. The second aim of the current study was to examine the main effect of the REDI intervention on growth in children's EF skills. It was anticipated that due to the language, emergent literacy, and particularly the social-emotional enhancements in REDI classrooms, intervention children would outperform control children in levels and rates of change in EF. Finally, the third aim of the current study was to also examine whether child characteristics, namely EF capacities, would moderate the sustained impact of the REDI intervention on growth in children's EF skills. Consistent with prior REDI findings (Bierman, Nix et al., 2008), it was anticipated that children with low levels of EF might benefit most from the intervention.

Method

Participants

Participants in the proposed study include 356 children, recruited from Head Start (17% Hispanic, 25% African American, 58% European American; 54% girls) and followed longitudinally through third grade. At the start of the prekindergarten year, children were, on average 4.59 years old (SD = .32, range = 3.87 – 5.82). Reflecting their participation in Head Start, families were low-income, with an average income-to-needs ratio of .88. Most parents had graduated from high school or attained high-school equivalency certificates (65%), although many had not finished high school (33%). Very few (2%) had finished college. Based on Hollingshead (1975), most of the employed parents were working in unskilled or semi-skilled labor categories.

During the pre-kindergarten year, 192 children in this sample received the REDI preventive intervention and the other 164 children were in the “usual practice” Head Start control group. Children were assessed at the beginning (pre-intervention) and end (post-intervention) of the pre-kindergarten year, as well as the end of each subsequent year kindergarten through third grade. When assessments were collected in the prekindergarten year, children attended 44 classrooms in 25 Head Start centers. As they transitioned to kindergarten through third grade, children were dispersed across numerous classrooms (ranging from 195 to 218), schools (ranging from 82 to 94), and districts (ranging from 31 to 37).

Procedures

Information regarding family background was collected during pre-kindergarten parent interviews, when informed consent for study participation was obtained. Parents were compensated financially for this interview. School-level student achievement scores and rates of students who qualified from free/reduced lunch were retrieved from state records. At the beginning and end of the pre-kindergarten year, as well as the end of each subsequent school year through third grade, trained examiners assessed the EF skills of children during individual test sessions held at school. APA ethical standards for the conduct of research were followed in this study, and all procedures were approved by the university IRB.

Measures

The developmental appropriateness of the tasks used to measure EF was evaluated annually between the beginning of pre-kindergarten and third grade. When necessary, EF tasks were modified, removed, or added to the battery. Care was taken to ensure that the core components of EF (working memory, inhibitory control, attention shifting) were assessed by at least one measure at each time point. The number of EF tasks administered at each time point ranged from four to five, with a total of nine different tasks (or versions) administered over the course of the study. Administration history is summarized in Table 1.

Backward Word Span. On the backward word span task (Davis & Pratt, 1996), which was administered from the beginning of pre-kindergarten through second grade, children were asked to repeat a list of words in backward order. The practice list and the first list each contained two words, and subsequent lists increased to a total of five words. The backward word span task assesses children's working memory skills. The total number of items the child got correct was used as the final backward word span score.

Peg Tapping. For the peg tapping task (Diamond & Taylor, 1996), which was administered from the beginning of pre-kindergarten through kindergarten, children were required to tap a pencil twice when the interviewer tapped once and to tap once when the interviewer tapped twice. After practice trials, children were administered a series of 16 mixed one-tap and two-tap trials. The peg tapping task reflects children's inhibitory control and working memory skills. The percentage of correct responses was used as the final score for the peg tapping task.

Dimensional Change Card Sort (DCCS). The standard version of the DCCS task (DCCS – Standard; Frye, Zelazo, & Palfai, 1995), which was administered from the beginning of pre-kindergarten through kindergarten, involved target cards that varied along the dimensions of color and shape (e.g., red and blue, rabbits and boats). After learning to sort the cards according to one dimension (shape or color), the children were asked to sort the cards according to the other dimension. The standard version consisted of six trials. The percentage of correct post-switch trials was used as the final score on DCCS – Standard.

The border version of the DCCS task (DCCS – Border; Zelazo, 2006), which was administered to children in second grade, required children to pass the standard version of the DCCS, and then presented them with additional challenges. Specifically, additional test cards with black borders were added to the target cards. If the target card had a black border, the child was instructed to play the color game. In the color game, the child sorted according to color. If the stimulus card did not have a black border, the child was instructed to play the shape game. In the shape game, the child sorts according to shape. The border version consisted of 12 trials, with the rules repeated on each trial. The percentage of correct border trials was used as the final score on DCCS – Border. Performance on the standard and border versions of the DCCS is considered to reflect children's inhibitory control and attention shifting abilities (Zelazo, Carlson, & Kesek, 2008).

Walk-a-Line Slowly. In the walk-a-line slowly task (Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996), which was administered at each time point, the child was asked to walk along a piece of string taped to the floor as the examiner timed them. The child was then asked to repeat the task twice, walking as slowly as possible. The final score for walk-a-line slowly was calculated by subtracting the child's time on the initial trial from the average of the two slower trials. Due to some extreme outliers, final scores were truncated at three standard deviations above the sample mean. The walk-a-line slowly task is considered to assess children's inhibitory control.

Operation Span. In the operation span task (Willoughby et al., 2010), which was administered in first and second grade, the child was presented with images of houses with different animals and colors inside and was instructed to name the animal and color. Then, the child was presented with images of empty houses and instructed to recall either the animal or color in each house. The task increased in difficulty from two to four houses. The total number of items the child got correct was used as the final operation span score. The operation span task is considered to assess children's working memory skills.

Number Stroop. The number stroop task (Bull & Scerif, 2001), which was administered in first and second grade, required children to name the quantity of items (e.g., one, two, three, or four) in a target row across three conditions. The first was a baseline condition in which the child was required to name the quantity of the Xs (e.g., XX or XXXX) in each row. The second condition was a congruent condition in which the child was required to name the quantity of numbers in each row. In the congruent condition, the quantity corresponded to the printed number (e.g., 22 or 4444). The third condition was an incongruent condition that again required the child to name the quantity of numbers in each row. However, the quantity and the printed number did not correspond (e.g., 11 or 3333). In each condition, the child was asked to respond as quickly as possible, correct any errors made, and was timed by the examiner with a stopwatch. The average time to complete the incongruent trials was used as the final score for number stroop, with lower times reflecting better performance. For analyses, time scores were reversed such that higher times scores reflected better performance, similar to the other EF measures. The number stroop task is considered a measure of children's inhibitory control.

Backward Digit Span. The backward digit span task (Davis & Pratt, 1996), which was administered in third grade, required children to repeat a list of numbers in backward order (e.g., If I saw '1 – 3,' you say '3 – 1'). The first list consisted of two numbers and subsequent lists of words increased to as many as eight numbers. The total number of items the child got correct was used as the final backward digit span score. The backward digit span task is considered to assess children's working memory skills.

Trail-Making. The trail-making task (Army Individual Battery Test, 1944) was administered in third grade. On part A of the trail-making task, which provides a baseline measure of processing speed, children were required to connect 15 circled numbers in order (e.g., 1 – 2 – 3 – 4) using a pencil. On part B, children were required to connect 15 circled numbers and letters in alternating order (e.g., 1 – A – 2 – B). Completion time was recorded for each part. Children's performance on part B of the trail-making task is considered to reflect their attention shifting and flexibility skills, with lower times reflecting better performance. For analyses, times were reversed to parallel other EF measures.

REDI Intervention. The REDI intervention was delivered by Head Start teachers in their classrooms. As described, REDI employed a multi-component approach to promote children's academic and social-emotional school readiness. First, to foster children's early language and emergent literacy skills, teachers were provided with an interactive reading program to be delivered four times per week, "sound games" activities to be delivered three times per week, and alphabet center activities to be delivered four times per week. Second, to promote children's social-emotional, self-regulatory, and EF skills, teachers were provided with the Preschool

PATHS Curriculum (Domitrovich et al., 2005; Domitrovich et al., 2007). This curriculum consists of 33 lessons seeking to foster children's (a) prosocial friendship skills, (b) emotional understanding, (c) self-control, and (d) problem-solving skills. In addition to presenting these lessons, teachers also fostered children's self-regulation by employing positive classroom management strategies, emotion coaching, and induction strategies throughout the Head Start day. Parents also received a set take-home materials, including DVDs overviewing REDI concepts and PATHS curriculum handouts.

Missing Data

Retention rates across the study were high, with at least some EF data collected for 94% of the original sample at the end of pre-kindergarten, 93% at kindergarten, 91% at first grade, 87% at second grade, and 83% at third grade. Most of the children in the sample (77%) had complete EF data. Others were missing one or more of the EF measures from one (10% of the sample), two (3%), three (4%), four (3%), or five (3%) of the six time points. All of the children had data from at least one time point and were thus included in the study analyses. During latent growth curve modeling in Mplus and latent class growth analysis in SAS, missing data was handled using a full information maximum likelihood approach.

Analytic Plan

To examine the sustained impact of the REDI intervention on the development of EF from pre-kindergarten through third grade, two longitudinal approaches were used: latent growth curve modeling and latent class growth analysis.

Latent Growth Curve Modeling. In latent growth curve modeling, the goal was to model the normative development of EF in the control group, and then to examine whether the intervention accounted for EF growth over and above the normative developmental process. The strategy prescribed by Curran and Muthen (1997; Muthen & Curran, 1999) for the application of latent growth curve modeling in developmental preventive interventions was adjusted to address issues with the measurement of EF in the current study. Specifically, as in many developmental studies, the developmental appropriateness of the tasks used to measure EF was evaluated across time and, when necessary, EF tasks were modified, removed, or added to the battery (Hancock & Buehl, 2008). Confirmatory factor analysis (CFA) was integrated into the analytic process and used to test for longitudinal measurement invariance and multi-group invariance, thereby increasing confidence that the same latent EF construct was measured across time, and across the control and intervention groups.

The analytic plan for latent growth curve modeling in the current study included five steps. First, a first-order CFA was estimated within the control and intervention groups separately to test for longitudinal measurement invariance in the latent EF construct. Second, and building on the first-order CFAs, a second-order LGM with shifting indicator variables (Hancock & Buehl, 2008) was estimated within the control group in order to capture the level, shape, and variability of the normative developmental process of EF. A parallel model was estimated within just the intervention group to characterize the development of EF for children who received the intervention. Third, a multi-group CFA was conducted to test for invariance in the measurement of the latent EF constructs across the control and intervention groups. In the fourth step, a multi-group LGM was estimated with the control and intervention groups simultaneously. Ultimately, the multi-group LGM allowed for the partitioning of the portion of growth in the latent EF construct that was due to normative development, versus the portion of growth that was due to the intervention, thus reflecting the main effect of the intervention. The fifth and final step in the LGM analyses was to test for a possible interaction between initial EF status and the intervention. Each step of this latent growth curve modeling process was fit using Mplus Version 7.6 (Muthen & Muthen, 1998-2012) data analytic software, which was adequate for dealing with non-normal data.

Latent Class Growth Analysis. In addition to latent growth curve modeling, a person-oriented modeling approach (Nagin, 1999; 2005) was also applied to examine whether the effect of the REDI intervention differed for subgroups of children within the sample. Latent class growth analysis addressed the question of whether subgroups of children (characterized by EF trajectory classes) responded better to the intervention than others. To address this question, developmental trajectories of EF were estimated using latent class growth analysis, which clusters children into a small number of trajectory classes, each of which can be examined independently for an intervention effect. Each step of the latent class growth analysis was conducted using *proc traj* (Jones, Nagin, & Roeder, 2001) in SAS.

Results

Preliminary Analyses

Table 1 presents descriptive statistics for the raw EF variables for the entire sample, as well as for the intervention and control groups separately. Table 2 presents correlations among the raw EF variables. Due to non-normality in the distributions of several variables, strategies were used to address non-normality in each set of analyses. Specifically, latent growth curve modeling was conducted using robust maximum likelihood (MLR) estimation in Mplus (Muthen & Muthen, 1998-2012), which is capable of dealing with non-normally distributed variables. And prior to applying the latent class growth analysis, raw EF variables were transformed using Box-Cox maximum power transformations (Box & Cox, 1964) in order to obtain more normal scores. The transformed EF scores were then standardized and composited within each time point, yielding overall EF composites for use in latent class growth analysis. The EF composite variables had strong distributional qualities and longitudinal stability. Correlations among the EF composites are presented in Table 4.

Latent Growth Curve Modeling

Longitudinal Invariance. The first step latent growth curve modeling was to estimate a first-order CFA within the control and intervention groups separately. In this model, the latent EF factors were conceptualized to represent the same underlying construct over time even though the measures (or indicators) of EF changed. As prescribed by Hancock and Buehl (2008), latent EF factors were linked to their temporal neighbors through common indicator variables, as shown in Figure 1. This was accomplished by constraining the factor loadings and then the intercepts of common measures to be equal across time. This process provides a strong test of longitudinal measurement invariance over time (Meredith, 1993).

The fit of the CFA model was evaluated using the Comparative Fit Index (CFI; with values above .90 considered adequate), the Root Mean Square Error of Approximation (RMSEA; with values below .10 considered adequate), and the Standardized Root Mean Square Residual (SRMR; with values below.10 considered adequate). The RMSEA prioritizes parsimony, the SRMR serves as an index of absolute fit to the data, and the CFI can be used to assess incremental improvements in fit (Hancock, 2015).

Results for the initial CFA model with factor loadings of common measures constrained to be equal across time suggested reasonable fit to the data (CFI = .93, RMSEA = .04, SRMR = .08); however, an examination of modification indices revealed non-invariant factor loadings for Peg Tapping and DCCS at the end of preschool, and Backward Word Span in first grade. Given the possibility that ceiling effects reduced the validity of some of these measures, a series of respecified models were considered in which the factor loading constraints of these three measures were released one by one. These models resulted in incrementally improved fit to the data (CFI = .95, RMSEA = .03, SRMR = .06). A final model was fit with the intercepts of the remaining common measures constrained to be equal across time, yielding a good model fit (CFI = .94, RMSEA = .03, SRMR = .07), and suggesting partial longitudinal invariance (Byrne, Shavelson, & Muthen, 1989). This process of invariance testing was then repeated within the intervention group. Results similarly suggested the need to release the factor loading and intercept constraints of the same three variables, and doing so yielded a partially-invariant model of adequate fit (CFI = .91, RMSEA = .04, SRMR = .09), which is illustrated in Figure 2.

Developmental Process of EF. In the second step, a second-order latent growth curve model with shifting indicators was estimated within the control group, building on top of the first-order CFA model just described. The loadings on the second-order intercept factor were all fixed to 1.0 to reflect initial EF status at the start of pre-k, and loadings on the second-order linear slope factor were set to 0.0, 0.5, 1.5, 2.5, 3.5, and 4.5 to reflect the unequally spaced assessments between the start and end of pre-k, and the equally spaced assessments between the ends of pre-k and third grade, as shown in Figure 3. Means and variances were estimated for the intercept and linear slope growth factors, and the correlation between the intercept and slope was freely estimated. Fit of the latent growth curve models was evaluated using the RMSEA and SRMR only, as the CFI is not appropriate for use in models with a mean structure (Hancock, 2015).

This second-order latent growth curve model with shifting indicators estimated within the control group resulted in adequate fit (RMSEA = .04, SRMR = .07). There was a significant mean estimate for the linear slope factor ($p < .01$) that reflected a group-level developmental increase in EF over time. There were also significant variance estimates in both the intercept ($p < .01$) and linear slope ($p < .05$) factors that reflected the presence of important inter-individual differences in the initial status of and change in EF over time, respectively. As such, results suggested both meaningful group and individual differences in the development of EF within the control group. This represented the normative developmental process of EF as it existed without intervention. A model with an additional quadratic slope factor was also estimated, however the quadratic factor did not add meaningfully to the growth of EF over and above the linear slope factor. The second-order latent growth curve model with shifting indicators was also estimated within the intervention group, resulting in a model of adequate fit (RMSEA = .05, SRMR = .09). Similar to the control group, there was a significant mean estimate for the linear slope factor ($p < .01$), and significant variance estimates for both the intercept ($p < .01$) and linear slope ($p < .05$) factors. A model with a quadratic slope factor was also estimated, but again did not add meaningfully to the linear growth factor.

Multi-group Invariance. The third step was to test for multi-group invariance. To do so, the first-order CFA model described earlier was estimated within the control and intervention groups simultaneously. This model resulted in adequate fit to the data (RMSEA = .04, SRMR = .09), increasing confidence that the same underlying EF construct was being measured across time, as well as across groups.

Intervention and Interaction Effects. In the fourth step, the linear slope factor previously identified in the control group was estimated within the two groups simultaneously, with the factor means, variances, and covariances equated across the two groups. These constraints identified the portion of growth in the intervention group that was attributable to the normative developmental process of EF. In addition, a second linear slope factor unique to the intervention group was added, and the mean and variance of this intervention growth factor were estimated freely. This factor was designed to capture any intervention effect that existed above and beyond the normative developmental process of EF that was observed in the control group. The latent growth curve model fit in the control group (with normative growth factor only) is presented in Figure 4, and model fit in the intervention group (with normative plus intervention growth factor) is presented in Figure 5. The multi-group model showed adequate fit to the data (RMSEA = .05, SRMR = .09). Of greatest importance, the mean estimate of the linear slope factor for the intervention group was not significant (p = .71), suggesting that the intervention did not have a significant main effect on growth in EF over and above the normative developmental process. The fifth and final step of the latent growth curve modeling process addressed the question of whether the effect of the intervention varied as a function of initial EF status. To test for this possible moderation effect, the intervention linear slope factor was regressed on the intercept factor within the intervention group only, as shown in Figure 6. Results suggested, however, that the regression parameter was not significant (p = .85), suggesting initial EF status did not change the impact of intervention on EF. However, as prior research has indicated, it was possible that the intervention had significant effects on EF for some subgroups within the sample. To explore this possibility, latent class growth analysis was conducted.

Latent Class Growth Analysis

The EF composite variables described previously were submitted to latent class growth analysis. In latent class growth analysis, models with two to five developmental trajectory classes of EF were estimated. Each developmental trajectory class was initially specified with an intercept (set at third grade) and linear, quadratic, and cubic growth parameters. The Bayesian

Information Criterion (BIC), posterior probabilities, and size of the smallest trajectory class were each used to inform model selection (and corresponding number of developmental trajectories classes).

Information for models with two to five classes are summarized in Table 5. A three-class model was chosen as the best model. In the model estimation, the BIC scores continued to improveafter three groups had been identified (higher BIC scores considered better using the current estimation approach). However, after three groups, the smallest trajectory classes in the four- and five-class model solutions contained just 5.40 and 4.69% of the sample, respectively. The three-class solution was selected for parsimony, and because the class sizes in larger models were too small for the examination of within class intervention effects.

Figure 7 illustrates the three trajectory classes, each of which was specified with an intercept and a linear slope parameter in the final model. One group, termed “high,” comprised 28% of the entire sample (n = 99), was persistently around one standard deviation above the sample EF mean over time, and had a significant negative slope. A larger group, termed “moderate,” comprised 58% of the sample (n = 207), was around the sample mean over time, and had a significant positive slope. And the smallest group, termed “low,” comprised 14% (n = 50) of the sample, scored persistently around one standard deviation below the sample mean over time, and had a significant negative slope. Moderate posterior probabilities were high across the classes (.92 - .94), suggesting strong membership classification. Importantly, chi-square tests revealed that there were no significant differences in the prevalence rates of intervention versus control children assigned to the three classes.

To test the impact of the intervention, intervention status was assigned to children at the end of the pre-kindergarten year and remained with them for all other time points in the trajectories. The impact of the intervention on the intercept parameter reflected the difference between the intervention and control groups in the level of EF at third grade, whereas the impact on the slope parameter reflected the difference between the two groups in the rate of change in EF over time. The impact of the intervention within each trajectory class is summarized in Table 6, and illustrated in Figure 8. Results indicated that the intervention had a significant positive impact on the intercept and linear slope parameters for children in the low trajectory class. Specifically, children in the low trajectory class who received the intervention had steeper positive rates of change between the ends of pre-k and third grade that accrued in EF scores in third grade that were approximately two-thirds standard deviation higher than children who did not receive the intervention. The intervention also had a significant positive impact on the intercept parameter for children in the high trajectory class. Specifically, children in the high trajectory class who received the intervention had EF scores in third grade that were approximately one-third standard deviation higher than children who did not receive the intervention. In contrast, results suggested that the intervention had a slight but significant negative impact on the linear slope of children in the moderate EF trajectory class. However, the difference in rate of change did not yield a significant difference in EF levels at the end of third grade.

Discussion

The current study is compelling in demonstrating the sustained impact of the REDI intervention on EF skill development for children with low and high EF skills. It is the first study to find that preschool interventions can have effects on EF that last into middle childhood, and offers insights for future research in this area.

Sustained Intervention Effects

Low EF Class. Of critical importance, latent class growth analysis revealed that children in the low EF class who received the REDI intervention outperformed their peers who did not. Specifically, these children showed a steeper rate of growth over time as well as a higher level of EF at third grade (by approximately two-thirds of a standard deviation). This finding is consistent with prior REDI findings that children with low EF benefited most from the intervention on some emergent literacy and social-emotional outcomes, including increased social competence and reduced aggression (Bierman, Nix et al., 2008).

An interesting but unexplored hypothesis to explain this effect is that due to heightened stress exposure and/or a lack of structure and stimulation in the early environment, children in the low EF class were delayed and dysregulated entering preschool (see Blair, 2010). As such, the social-emotional curriculum and strategies used in REDI classrooms to provide structure and support may have provided much needed remedial help to children with low EF. There are reasons to believe that the REDI intervention would be optimal for dysregulated children. Using the Preschool PATHS curriculum and strategies, classroom teachers established predictable rules and routines for the classroom at large, provided children with explicit instruction and role-play opportunities to foster emotional understanding and self-regulation, and used warm support and scaffolding to build children's capacities to engage in a socially-competent and regulated manner throughout the day. These social-emotional and self-regulation supports may have been particularly beneficial to children with delayed EF, allowing them to activate and use their EF skills at an optimal level as they navigated the day-to-day challenges of the preschool setting, thus fostering EF further growth. In addition, as part of the language and emergent literacy curriculum and strategies, teachers engaged children in dialogic reading and were taught to use active listening and language expansions to support the development of children's reasoning, memory, and planning skills. The promotion of basic language, emergent literacy, and other essential cognitive skills may also have enhanced children's regulatory functioning. More work is needed in order to better understand the nature of this effect at the low end of EF, but it suggests the possibility that social-emotional interventions may be beneficial for the EF skill development of delayed and dysregulated children.

High EF Class. An interesting finding in the current study was that in addition to the intervention effect found at the low end of EF, intervention children with high EF also showed higher levels of EF at third grade compared to control children. One hypothesis for this somewhat surprising result is that intervention children with high EF were well-regulated (cognitively and behaviorally) and thus particularly suited to take advantage of the enriched instructional content provided in REDI classrooms.

Previous research has demonstrated that EF skills are directly and indirectly associated with gains in academic achievement (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Sasser et al., 2014). In a direct pathway, strong EF skills (working memory, inhibitory control, and attention shifting) are thought to enhance cognitive capacities such as reasoning and problem-solving that are essential for the learning process. In an indirect pathway, the link between EF skills and academic learning is thought to be mediated in part by children's learning-related behaviors, such as cooperation, attention, motivation, and persistence in the classroom (Sasser al., 2014). In the current study, it is possible that high EF skills enhanced children's cognitive and behavioral engagement in the preschool classroom, and that the enriched content and support provided in REDI classrooms, including PATHS lessons, dialogic reading activities, alphabet games, and structured and warm support, advanced intervention children beyond their counterparts who did not receive the enrichments. Conceptually, as children activate and use EF as part of the learning process, EF skills are strengthened in something of a feedback loop (Blair, 2010). Some recent developmental and intervention work suggests that this might be the case. For instance, academic skills have been shown to predict subsequent EF above and beyond baseline EF (Welsh et al., 2010), and participation in an academic tutoring intervention has been shown to foster self-regulation and attention (Rabiner, Murray, Skinner, and Malone, 2010). Additional research is needed to replicate the current study findings, and to provide greater clarity regarding the processes by which preschool interventions boost EF within high EF children.

Moderate EF Class. The current study did not find a sustained intervention effect at third grade for children in the moderate EF trajectory class. That the intervention did not boost EF in a large subgroup of children explains the lack of a main effect of the intervention. One hypothesis for this pattern of findings is that perhaps children in the moderate EF class did not require the remedial support provided by the social-emotional components of the REDI intervention that may have benefited children in the low EF class, nor were they particularly primed to benefit from the enriched instructional content in REDI classrooms in the way that children in the high EF class may have been.

Latent Growth Curve Modeling

The current study is among the first to utilize a second-order latent growth model with shifting indicators with actual data (see Hancock & Buehl, 2008), and it is certainly the first to do so in the context of an intervention study. A common challenge to developmental research and intervention trials examining longer-term outcomes is that as children's skills grow over time, changes in measurement sometimes become necessary. The current study in particular spanned from early to middle childhood, a period characterized by remarkable growth in children's EF. The battery of EF tasks was thus adjusted developmentally. The latent growth curve modeling done in the current study demonstrated one way forward to researches who have had to adjust study measures based on developmental considerations, particularly in the study of EF.

An important study finding was that the first-order CFA models fit the data well, suggesting that the latent EF factors represented the same underlying construct over time. Although developmental researchers hope that repeated measures are tapping the same construct, the analytic approach used in the current study tested and confirmed that this was the case. Further, the normative developmental process of EF was estimated in the control group using second-order latent growth curve modeling, documenting that the latent EF factor showed significant positive growth following a linear pattern from early to middle childhood, and confirming systematic growth in children's EF over time. There were also significant individual differences in rates of growth in EF. Together, these findings suggest that EF, as a latent construct, can be adequately measured and tracked across developmental periods. Additionally, more work is needed to examine the correlates and consequences of individual differences in the normative developmental process of EF, which can help to further elucidate the role of EF within child development.

Latent growth curve modeling also offered a strong test of sustained intervention effects. Specifically, latent growth curve modeling was used to test whether the intervention had main or simple interaction (by initial EF status) effects on growth in children's EF over time. By testing whether the intervention added growth that was above and beyond the normative developmental process of EF, the application of latent growth curve modeling offered a developmentally sensitive and conservative test of these effects (Curran & Muthen, 1999). However, it is not uncommon for approaches such as latent growth curve modeling to miss meaningful intervention effects that occur within subgroups of children (Liu, Hedeker, Segawa, & Flay, 2009), and latent class growth analysis was used to test whether the intervention had its effects within different subgroups of children.

Strengths and Limitations

This study had several strengths that lend support to the findings. First, Head Start REDI was a randomized controlled trial, and the REDI intervention targeted multiple domains of school readiness using curriculum and strategies there were informed by intervention and developmental science. Second, in the current study, two longitudinal designs were used to test the sustained impact of the REDI intervention on the developmental process of EF.

Some limitations also warrant attention. First, given the interest in interventions for children experiencing economic adversity, the current study used a low-income sample of preschoolers. As such, study findings may not generalize to normative samples, or to other underrepresented subsamples for which questions regarding EF development and promotion may also be relevant (e.g., bilingual children, children with clinical ADHD or other disabilities). Second, the latent class growth analysis conducted in the current study was exploratory in nature, and the latent trajectory classes observed here (high, moderate, low) may not generalize to other data. More studies investigating the longitudinal growth in EF across developmental periods are certainly warranted. Third, latent class growth analysis relied on the use of an EF composite, an approach that does not adequately account for error in the measurement of the underlying construct. However, compositing has been used by others in this area of study (e.g., Welsh et al., 2010), and CFA results within the current study lent confidence to the use of an EF composite with study measures. The EF composites also showed good distributional characteristics and were stable over time.

Implications and Future Research

The promise of preschool interventions designed to promote self-regulation and EF is that by boosting “top-down” regulatory skills, the gap between low-income children and their middle income peers will close not only in childhood, but also beyond into adolescence and adulthood (Blair, 2002; Heckman, 2008). Despite a recent spike of interest in the promotion of EF skills in early childhood education, much work remains to be done, particularly in terms of the examination of sustained effects. The current study marks a step forward, documenting sustained effects on children’s EF skills into middle childhood.

There are several different perspectives on how to boost self-regulation and EF skills in the early school environment (see Bierman & Torres, 2015 for a recent review). Some of these intervention models have been designed with the promotion of self-regulation and EF as their primary target outcome, although to date efforts to promote EF by direct training have yielded disappointing findings, with little evidence of generalization to classroom or academic functioning (Bierman & Torres, in press; Diamond & Lee, 2011). By contrast, other interventions have as their primary goal the promotion of children’s school readiness skills, with EF skills as a secondary outcome. These intervention models have been designed to target early academic skills, the quality of the teacher-student relationship and classroom climate, and social-emotional learning. REDI, in fact, integrated several of these approaches to enhance Head Start programs. As such, it is difficult to say how the component parts resulted in the sustained impact on children’s EF skills.

REDI employed the Preschool PATHS curriculum and strategies in order to foster children's social-emotional and self-regulation skills. Based in neurocognitive development, the logic model underlying PATHS suggests that emotion regulation and social problem-solving are possible only when "top down" regulatory control effectively modulates "bottom up" reactive responding (Greenberg, 2006). Consistent with the hypothesized model, an earlier evaluation with second and third grade students found that PATHS fostered inhibitory control skills, and that improvement in inhibitory control partially mediated the impact of the PATHS program on subsequent externalizing and internalizing behavior (Riggs et al., 2006). Similarly, prior REDI findings demonstrated that the intervention boosted aspects of EF, and that these gains partially mediated intervention effects on children's social-emotional functioning (Bierman, Nix et al., 2008).

To target children's language and emergent literacy skills, REDI also employed dialogic reading activities, active listening and language expansions by teachers, and a set of carefully-sequenced alphabet games. Interventions directly targeting academic skill growth have been shown to also boost self-regulation skills (Rabiner et al., 2010), and it was thought in the current study that these intervention strategies may enhance children's reasoning, memory, and planning, and thereby foster EF. It is difficult to know the degree to which these strategies may have had direct or perhaps synergistic effects on children's EF skills. For instance, it is possible that the enhancement of language skills improved children's ability to recognize and communicate about emotions in themselves and others, and enhanced their self-regulation and social-problem solving capacities, thus promoting EF development (Bierman, Nix et al., 2008).

In addition, previous REDI findings have also shown that the intervention fostered high-quality teaching, and in so doing created a more positive classroom climate (Domitrovich et al., 2009). It has been posited that by making the school environment safer, more predictable, and more positive, preschool interventions can foster EF among children growing up in poverty (Blair, 2002; Ursache et al., 2013). CSRP, for instance, specifically targeted classroom climate by enhancing Head Start teachers' ability to handle everyday challenges (Raver et al., 2008). Results showed that intervention children had higher EF scores and lower inattention/impulsivity ratings than children in control classrooms, and these differences mediated the impact of the intervention on children's school readiness (Raver et al., 2011). However, despite some short term effects, CSRP has not yielded a sustained impact on children's adjustment to school (Li-Grining & Haas, 2010). More work is needed to better understand the role of classroom climate on children's EF development. More broadly, future research is needed to explore the benefits of the various intervention approaches that were utilized in REDI for children's EF growth and broader functioning over time.

A related and important question is whether moving EF in the preschool and early school years will result in promised gains across a broad range of functional outcomes in childhood, adolescence, and even adulthood. Few studies have addressed this issue, and only over very short periods of time (e.g., Bierman, Nix et al., 2008; Raver et al., 2011). The capacity of the Head Start REDI project and other future studies to follow children across developmental periods is critical. To adequately address these questions, researchers must adopt strong study designs capable of informing the field regarding the normative developmental process of EF, as well as intervention effects. Studies also need to employ EF measures that can adequately accommodate for skill growth across development. While the measurement of EF skills in the preschool period has progressed dramatically in the last decade (Garon & Bryson, 2008), few if any assessments have been designed with longer-term follow-up in mind, particularly spanning developmental periods. A final issue is the need to assess key behaviors across development that have been theoretically linked to EF (e.g., grades, graduation, employment, substance use/abuse, delinquency, violence). Research suggests that it is possible for meaningful effects to emerge later in development. The next step is to determine whether sustained gains in EF mediate functional outcomes.

Conclusions

There has been increased interest in children's EF skills over the past 20 years, with hope that by promoting EF skills, the outcomes of children of children growing up in poverty will be enhanced. The current study lends some support for claims that preschool preventive interventions can boost EF skills, documenting sustained effects from preschool into middle childhood. Still much work remains to be done to better understand how intervention approaches can be refined to promote EF skills in ways that have broad and far-reaching benefits into academic, social-emotional, economic, and health outcomes.

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Table 1. EF Task Administration History.

EF tasks	Time Point					
	Pre-K – Start	Pre-K – End	Kindergarten	1st Grade	2nd Grade	3rd Grade
Walk-a-line Slowly	X	X	X	X	X	X
Backward Word Span	X	X	X	X	X	
Peg Tapping	X	X	X			
DCCS – Standard	X	X	X			
Operation Span				X	X	
Number Stroop				X	X	X
DCCS – Border					X	
Digit Span						X
Trail-Making Task						X

Note: ‘X’ indicates that the measure was administered at the time point. Pre-K = Pre-kindergarten.

Table 2. Descriptive Statistics and Distributional Properties of Raw EF Variables.

EF Variable	Entire Sample M (SD)	REDI Intervention Group M (SD)	Control Group M (SD)	Skewness	Kurtosis
Pre-K – Start					
Walk-a-line Slowly	2.45 (4.05)	2.53 (4.21)	2.36 (3.87)	0.91	2.98
Backward Word Span	1.17 (0.47)	1.16 (0.44)	1.19 (0.50)	2.98	9.03
Peg Tapping	0.48 (0.37)	0.48 (0.38)	0.48 (0.37)	-0.07	-1.51
DCCS – Standard	0.51 (0.45)	0.50 (0.45)	0.52 (0.46)	-0.06	-1.83
Pre-K – End					
Walk-a-line Slowly	3.40 (4.00)	3.26 (4.05)	3.57 (3.95)	1.15	1.54
Backward Word Span	1.42 (0.63)	1.39 (0.62)	1.46 (0.63)	1.28	0.85
Peg Tapping	0.70 (0.33)	0.72 (0.33)	0.70 (0.34)	-1.11	-0.08
DCCS – Standard	0.67 (0.42)	0.71 (0.39)	0.63 (0.45)	-.08	-1.22
Kindergarten					
Walk-a-line Slowly	5.38 (5.45)	5.44 (5.75)	5.32 (5.10)	1.47	2.69
Backward Word Span	1.95 (0.68)	1.94 (0.70)	1.97 (0.66)	0.11	-0.65
Peg Tapping	0.88 (0.22)	0.88 (0.22)	0.88 (0.22)	-2.73	7.50
DCCS – Standard	0.89 (0.26)	0.89 (0.28)	0.90 (0.24)	-2.61	5.63
1st Grade					
Walk-a-line Slowly	8.32 (7.45)	8.56 (7.65)	8.05 (7.24)	1.67	2.93
Backward Word Span	2.32 (0.69)	2.36 (0.70)	2.29 (0.68)	0.31	0.38
Operation Span	13.83 (2.98)	13.62 (3.00)	14.07 (2.96)	-0.51	0.19
Number Stroop	33.66 (9.44)	34.27 (10.07)	32.99 (8.67)	-1.14	1.58
2nd Grade					
Walk-a-line Slowly	10.39 (9.44)	10.61 (9.28)	10.16 (9.61)	2.20	6.35
Backward Word Span	2.62 (0.74)	2.64 (0.72)	2.59 (0.76)	0.22	-0.20
Operation Span	15.34 (2.96)	15.20 (3.11)	15.48 (2.81)	-.71	0.14
Number Stroop	26.70 (7.79)	27.26 (8.16)	26.12 (7.39)	-1.29	1.62
DCCS – Border	0.76 (0.24)	0.74 (0.24)	0.77 (0.24)	-1.08	0.95
3rd Grade					
Walk-a-line Slowly	12.22 (11.79)	12.14 (11.26)	12.30 (12.35)	2.43	7.10
Number Stroop	21.93 (5.90)	22.20 (6.00)	-21.66 (5.82)	-1.18	1.03
Digit Span	5.68 (1.81)	5.66 (1.74)	5.71 (1.88)	0.31	2.16
Trail Making	56.76 (23.66)	56.86 (22.51)	56.65 (24.87)	-1.20	1.64

Note: Pre-K = Pre-kindergarten.

Table 3. Correlations among Raw EF Variables.

	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.
Pre-K – Start																								
1. Walk-a-line Slowly	.20	.28	.21	.48	.20	.29	.15	.30	.18	.17	.09	.23	.14	.15	.15	.22	.17	.04	.18	.06	.29	.14	.20	.08
2. Backward Word Span	-	.34	.25	.18	.47	.25	.17	.20	.28	.14	.08	.12	.19	.17	.17	.19	.15	.16	.15	.17	.12	.16	.23	.12
3. Peg Tapping		-	.37	.33	.41	.56	.32	.29	.34	.33	.14	.24	.20	.28	.28	.23	.15	.24	.26	.20	.15	.28	.26	.23
4. DCCS – Standard			-	.19	.29	.38	.40	.19	.33	.20	.23	.11	.26	.17	.15	.16	.21	.21	.25	.27	.13	.22	.23	.22
Pre-K – End																								
5. Walk-a-line Slowly				-	.21	.30	.18	.39	.24	.10	.15	.39	.17	.18	.17	.34	.09	.19	.23	.05	.41	.18	.17	.12
6. Backward Word Span					-	.35	.27	.20	.35	.23	.13	.20	.22	.25	.25	.34	.22	.21	.25	.20	.23	.30	.36	.20
7. Peg Tapping						-	.28	.28	.49	.44	.21	.29	.30	.31	.39	.28	.23	.30	.42	.34	.22	.48	.37	.29
8. DCCS – Standard							-	.17	.25	.15	.17	.23	.17	.18	.13	.23	.18	.20	.21	.21	.21	.12	.16	.22
Kindergarten																								
9. Walk-a-line Slowly								-	.25	.16	.14	.43	.25	.17	.21	.41	.14	.15	.26	.03	.38	.29	.19	.14
10. Backward Word Span									-	.32	.25	.24	.32	.24	.22	.29	.37	.28	.32	.22	.19	.35	.42	.32
11. Peg Tapping										-	.17	.24	.28	.19	.22	.19	.22	.18	.33	.16	.14	.31	.32	.23
12. DCCS – Standard											-	.19	.17	.14	.17	.18	.14	.25	.20	.24	.10	.15	.21	.17
1st Grade																								
13. Walk-a-line Slowly												-	.19	.15	.18	.48	.22	.18	.26	.14	.52	.21	.22	.15
14. Backward Word Span													-	.34	.17	.25	.22	.26	.23	.16	.27	.24	.37	.25
15. Operation Span														-	.24	.19	.15	.42	.34	.25	.12	.31	.36	.29
16. Number Stroop															-	.23	.20	.25	.56	.21	.16	.50	.26	.22
2nd Grade																								
17. Walk-a-line Slowly																-	.21	.22	.27	.11	.66	.23	.30	.17
18. Backward Word Span																	-	.21	.22	.15	.19	.25	.39	.17
19. Operation Span																		-	.35	.26	.17	.30	.29	.28
20. Number Stroop																			-	.29	.26	.66	.30	.31
21. DCCS – Border																				-	.09	.29	.27	.11
3rd Grade																								
22. Walk-a-line Slowly																					-	.21	.23	.16
23. Number Stroop																						-	.39	.31
24. Digit Span																							-	.22
25. Trail Making																								-

Note: Correlations with an absolute value greater than .11 are statistically significant, $p < .05$. Pre-K = Pre-kindergarten.

Table 4. Correlations among EF Composite Variable.

EF Composite	2.	3.	4.	5.	6.
1. Pre-K – Start	0.64	0.50	0.43	0.42	0.41
2. Pre-K – End	-	0.58	0.58	0.57	0.56
3. Kindergarten		-	0.57	0.60	0.57
4. 1st Grade			-	0.69	0.69
5. 2nd Grade				-	0.70
6. 3rd Grade					-

Note: Correlations with an absolute value greater than .11 are statistically significant, $p < .05$.

Pre-K = Pre-kindergarten.

Table 5. Latent Class Growth Analysis Model Parameters.

No. of Classes	BIC	Range of Posterior Probabilities	Size of Smallest Class
2	-2503.27	.92-.94	48.14%
3	**-2390.91**	**.92-.94**	**15.81%**
4	-2357.32	.89-.94	5.40%
5	-2337.21	.80-.91	4.69%

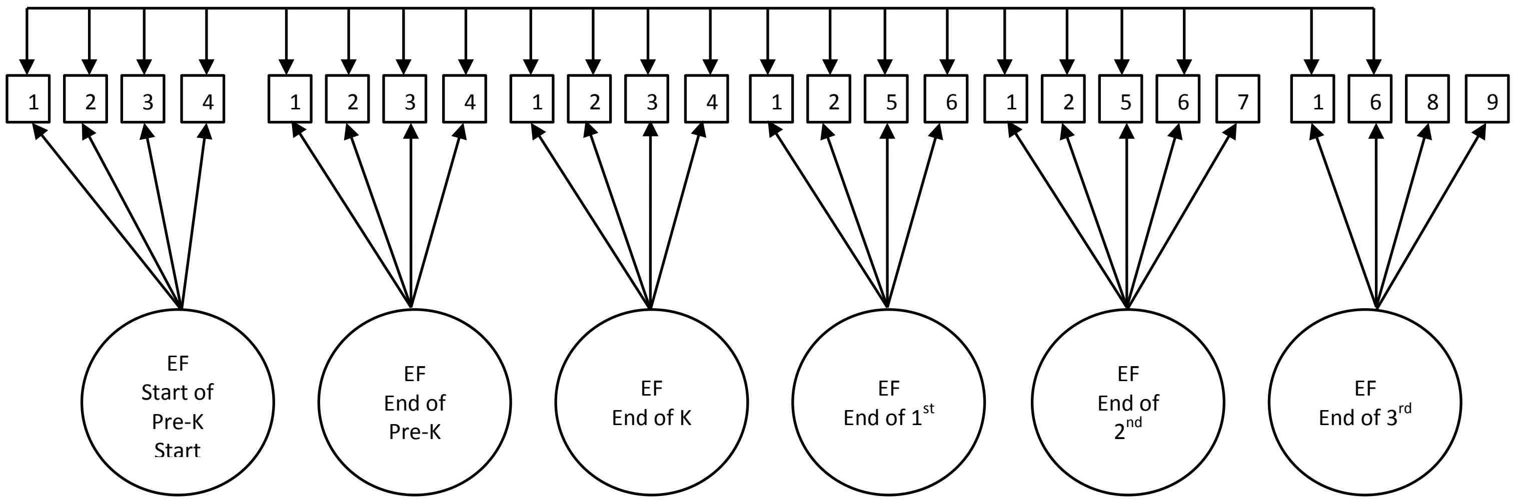
Note. Boldface type indicates the selected model.

Table 6. Parameter Estimates Intervention Effects within Latent Trajectory Classes.

	High EF Class	Average EF Class	Low EF Class
Parameter	Estimate (SE)	Estimate (SE)	Estimate (SE)
Intercept	0.67 (0.09)**	0.05 (0.06)	-1.80 (0.16)**
Slope	-0.07 (0.02)**	0.07 (0.02)**	-0.18 (0.04)**
Intervention on Intercept	0.32 (0.12)*	-0.13 (0.09)	0.66 (0.19)**
Intervention on Slope	0.05 (0.04)	-0.06 (0.03)*	0.22 (0.06)**

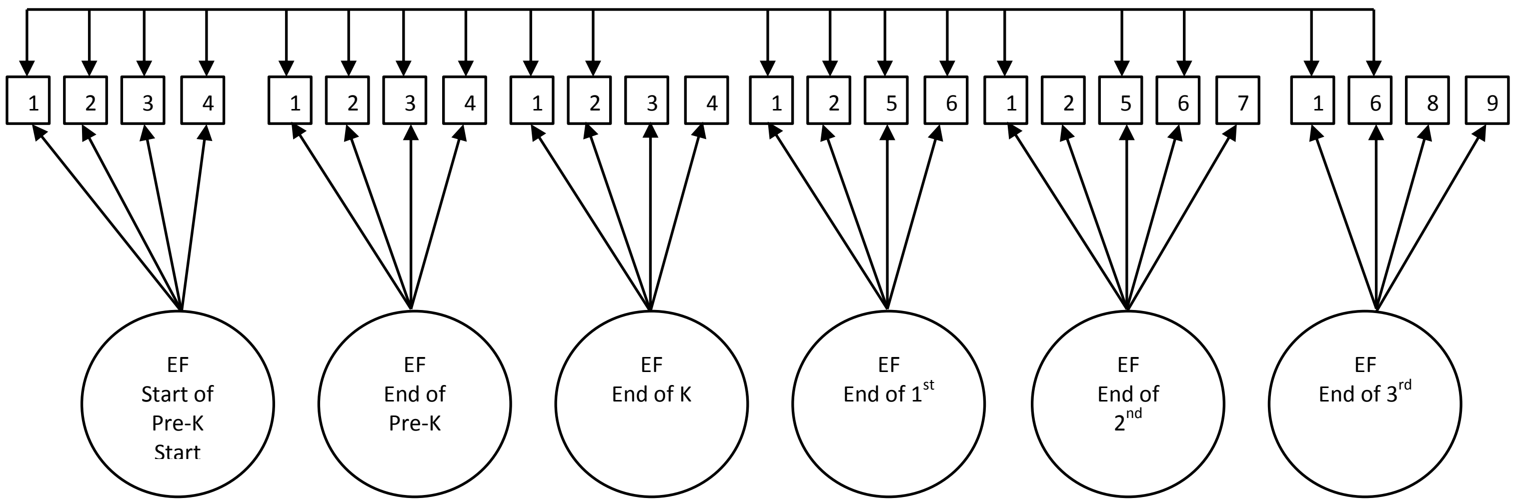
Note: ** $p < .01$, * $p < .05$.

Figure 1. *Hypothesized CFA Model.*



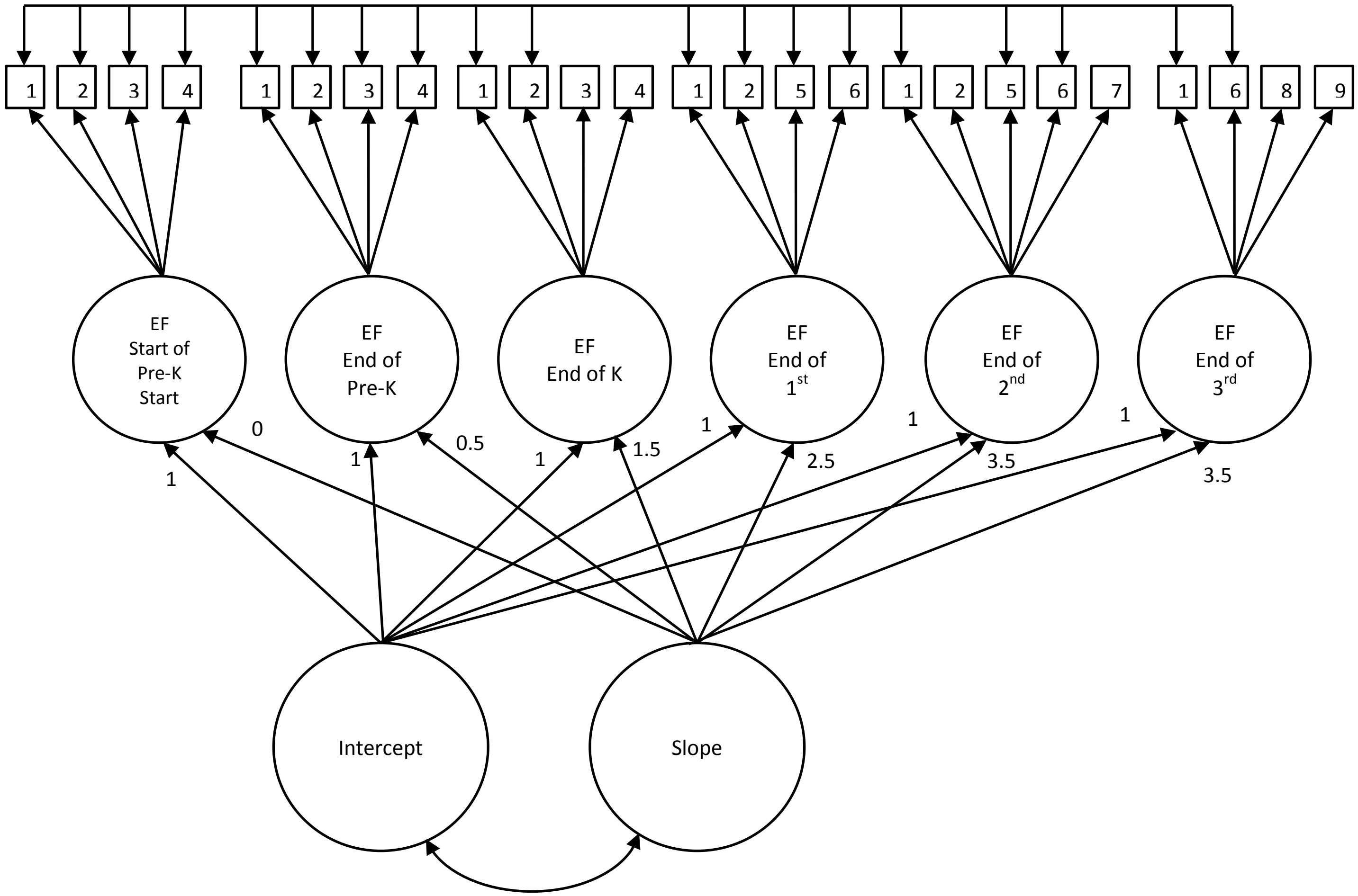
Note: 1 = Walk-a-line Slowly; 2 = Backward Word Span; 3 = Peg Tapping; 4 = Dimensional Change Card Sort – Standard Version; 5 = Operation Span; 6 = Number Stroop; 7 = Dimensional Change Card Sort – Border Version; 8 = Digit Span; 9 = Trail Making. Error terms for observed indicators and residual error terms of and covariances among latent EF factors omitted to simplify model presentation.

Figure 2. *Final CFA Model Fit within Control and Intervention Groups Separately*.



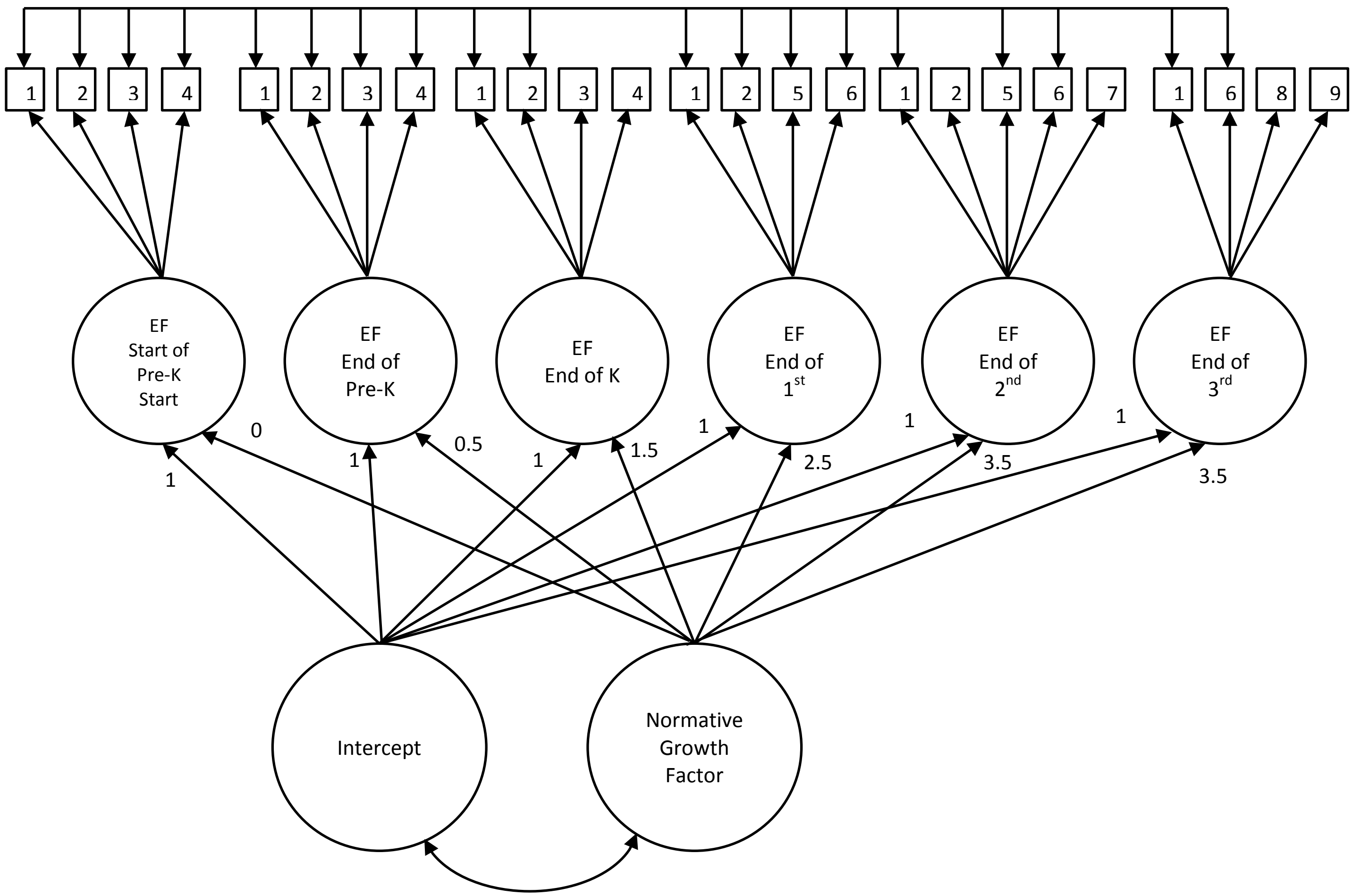
Note: 1 = Walk-a-line Slowly; 2 = Backward Word Span; 3 = Peg Tapping; 4 = Dimensional Change Card Sort – Standard Version; 5 = Operation Span; 6 = Number Stroop; 7 = Dimensional Change Card Sort – Border Version; 8 = Digit Span; 9 = Trail Making. Error terms for observed indicators and residual error terms of and covariances among latent EF factors omitted to simplify model presentation.

Figure 3. *Second-order Latent Growth Curve Model with Shifting Indicators Estimated within the Control and Intervention Groups Separately*.



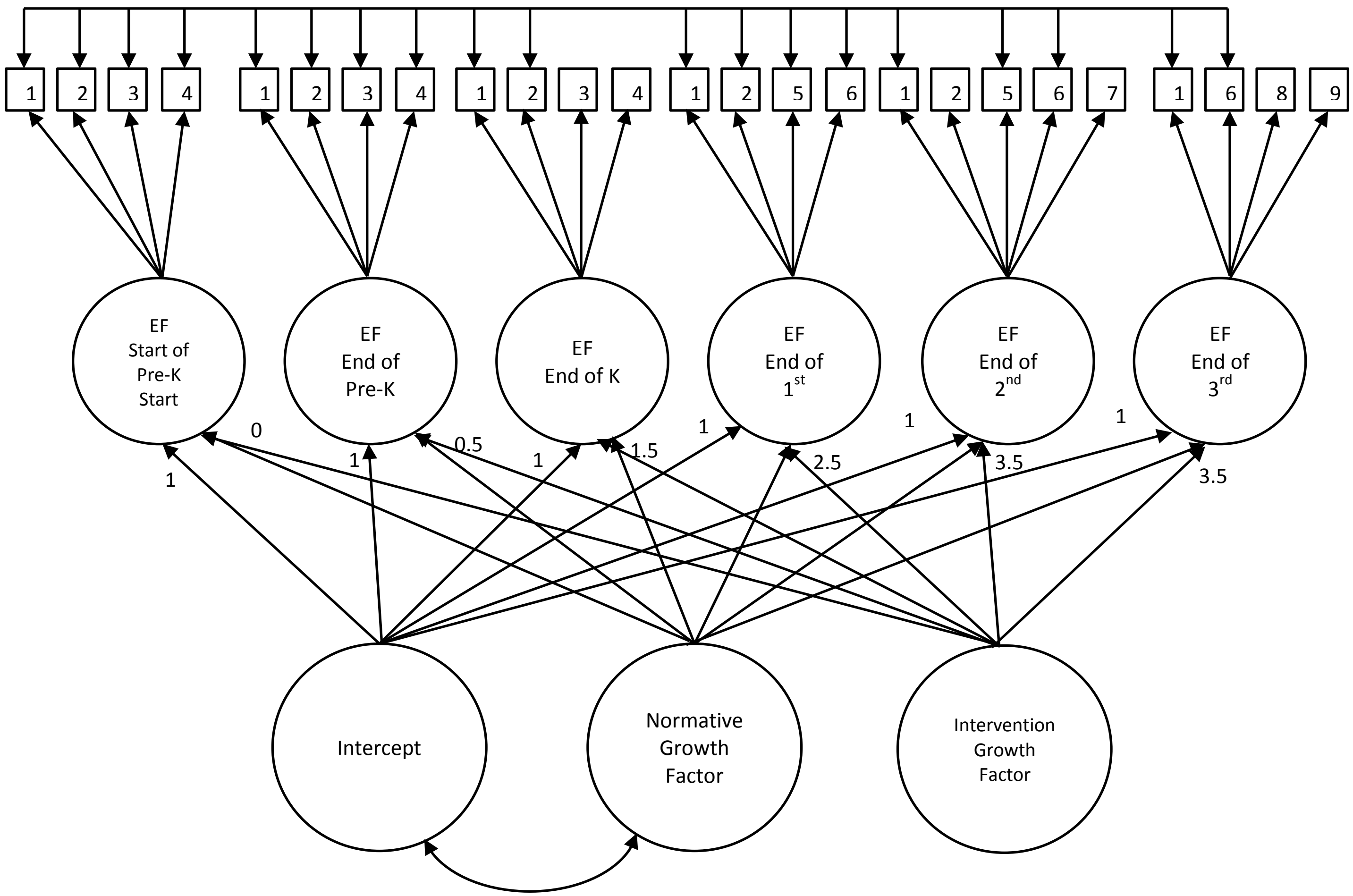
Note: 1 = Walk-a-line Slowly; 2 = Backward Word Span; 3 = Peg Tapping; 4 = Dimensional Change Card Sort – Standard Version; 5 = Operation Span; 6 = Number Stroop; 7 = Dimensional Change Card Sort – Border Version; 8 = Digit Span; 9 = Trail Making. Error terms for observed indicators and residual error terms of and covariances among latent EF factors omitted to simplify model presentation.

Figure 4. *Second-order Latent Growth Curve Model with Shifting Indicators Estimated within the Control Group to Account for Normative EF Development.*



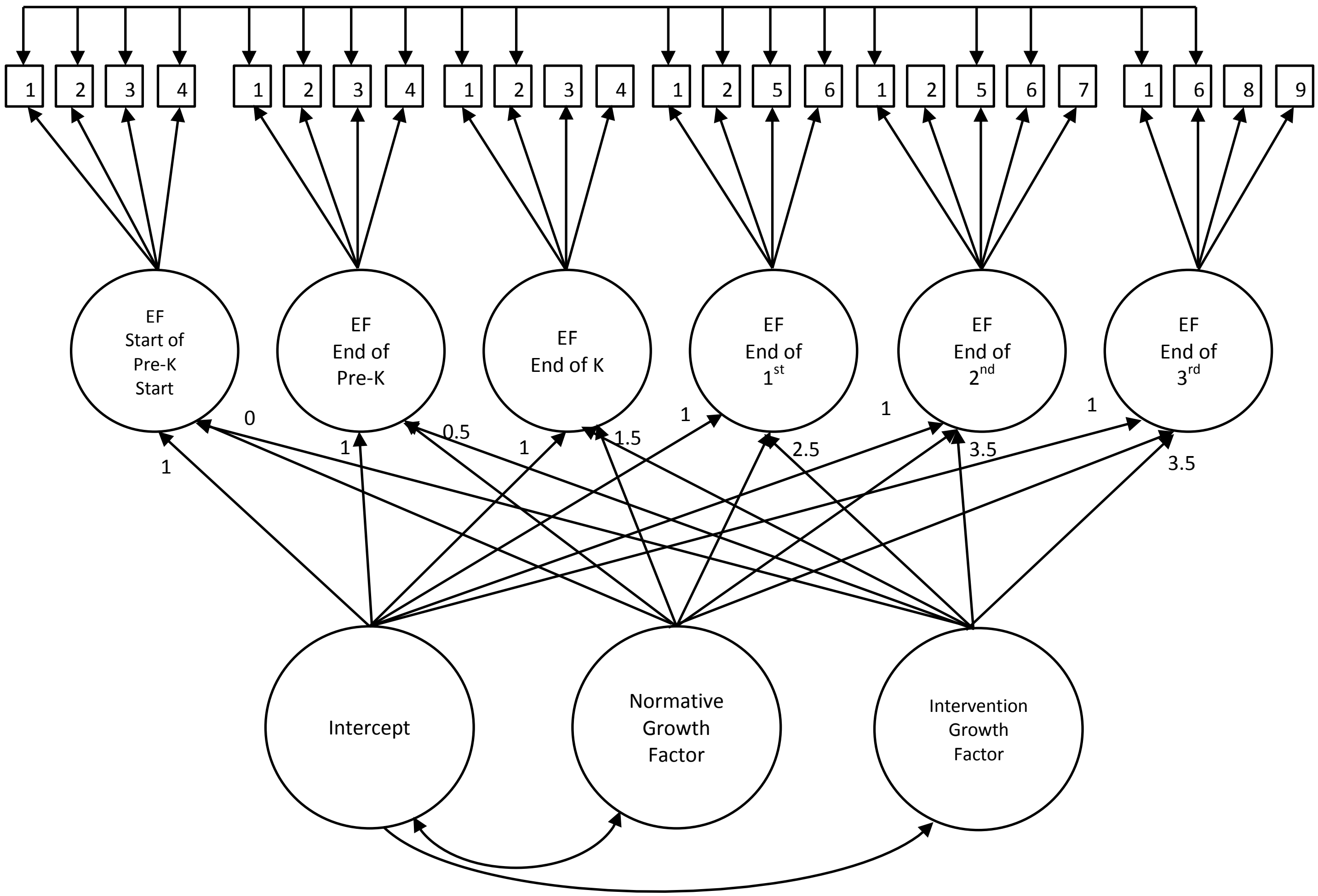
Note: 1 = Walk-a-line Slowly; 2 = Backward Word Span; 3 = Peg Tapping; 4 = Dimensional Change Card Sort – Standard Version; 5 = Operation Span; 6 = Number Stroop; 7 = Dimensional Change Card Sort – Border Version; 8 = Digit Span; 9 = Trail Making. Error terms for observed indicators and residual error terms of and covariances among latent EF factors omitted to simplify model presentation.

Figure 5. *Second-order Latent Growth Curve Model with Shifting Indicators Estimated within the Intervention Group to Model EF Development Due to Intervention.*



Note: 1 = Walk-a-line Slowly; 2 = Backward Word Span; 3 = Peg Tapping; 4 = Dimensional Change Card Sort – Standard Version; 5 = Operation Span; 6 = Number Stroop; 7 = Dimensional Change Card Sort – Border Version; 8 = Digit Span; 9 = Trail Making. Error terms for observed indicators and residual error terms of and covariances among latent EF factors omitted to simplify model presentation.

Figure 6. *Second-order Latent Growth Curve Model with Shifting Indicators Estimated within the Intervention Group to Model EF Development Due to Intervention and to Test for Interaction.*



Note: 1 = Walk-a-line Slowly; 2 = Backward Word Span; 3 = Peg Tapping; 4 = Dimensional Change Card Sort – Standard Version; 5 = Operation Span; 6 = Number Stroop; 7 = Dimensional Change Card Sort – Border Version; 8 = Digit Span; 9 = Trail Making. Error terms for observed indicators and residual error terms of and covariances among latent EF factors omitted to simplify model presentation.

Figure 7. *Latent EF Trajectory Classes.*

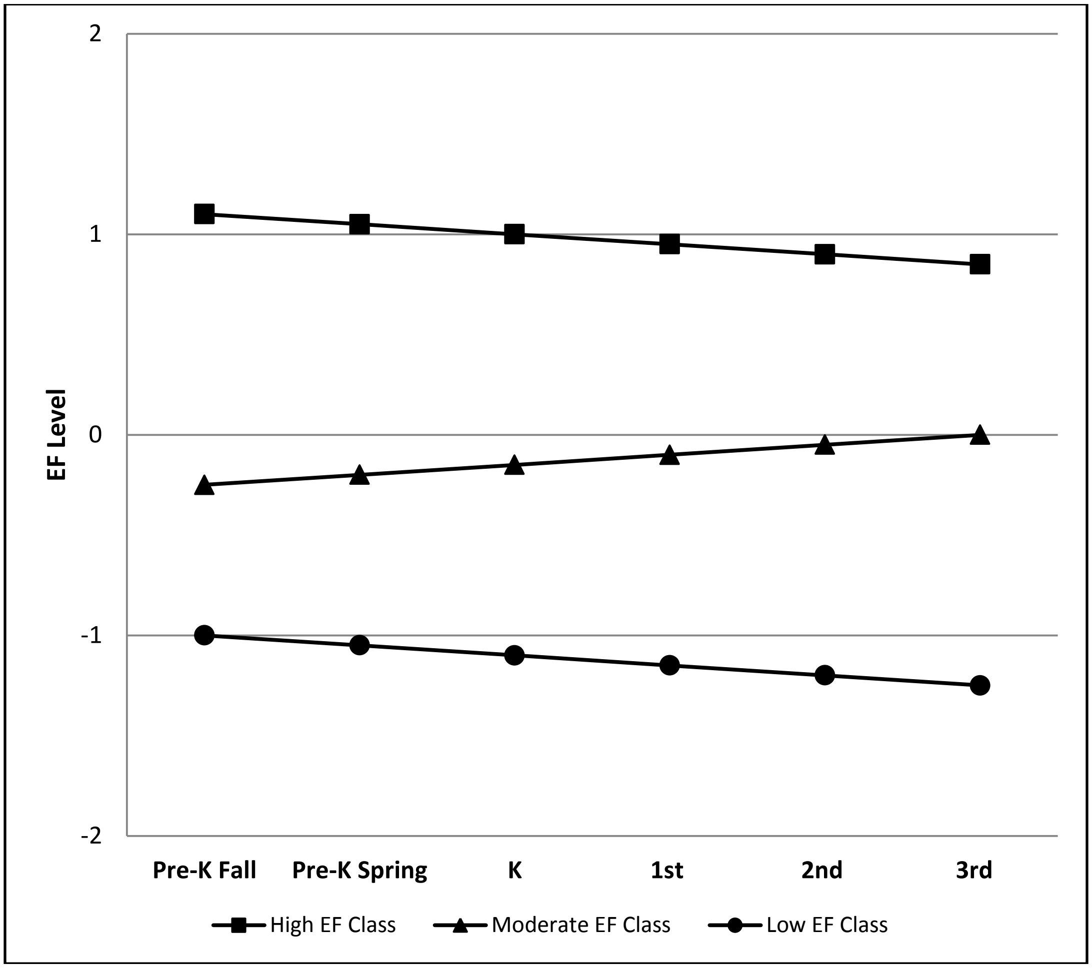
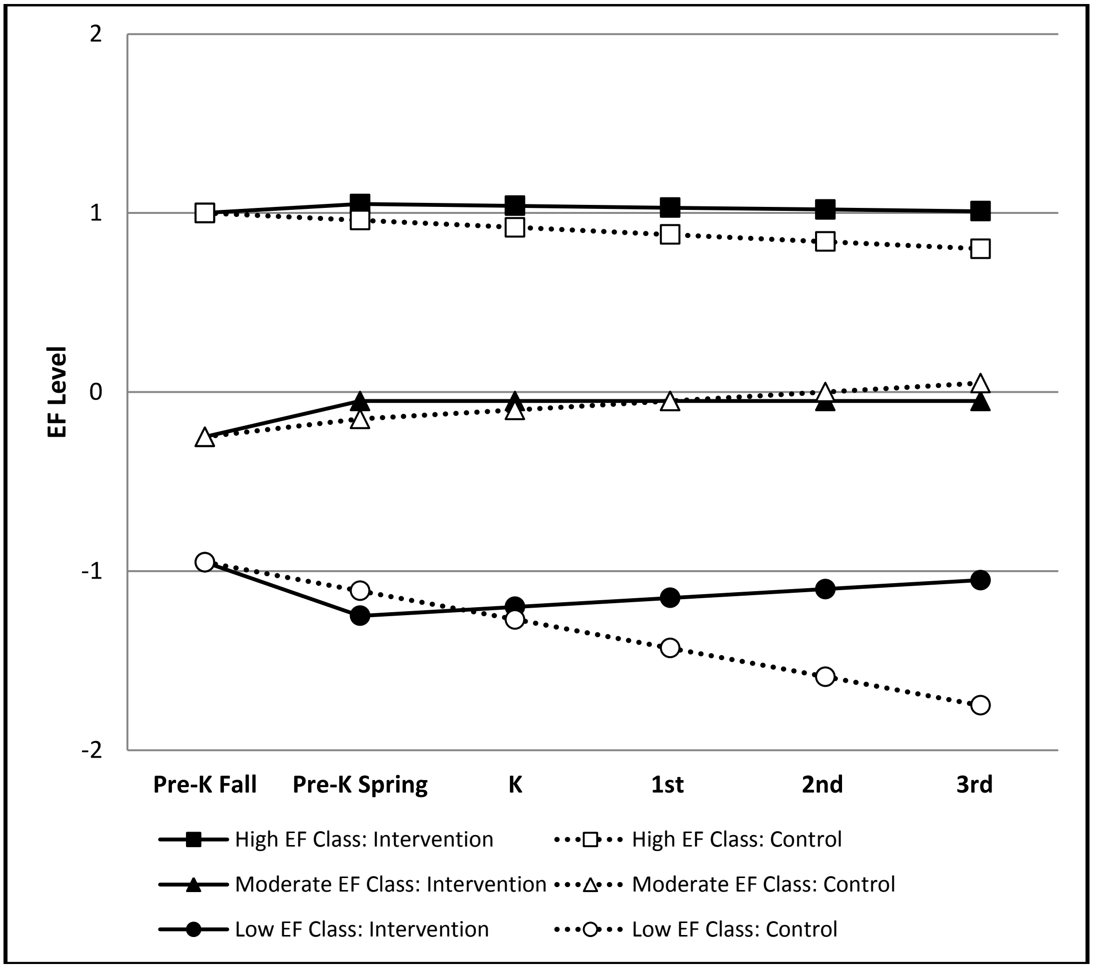


Figure 8. *Sustained Intervention Effects within Latent EF Trajectory Classes.*



Vita

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Education

Anticipated 2016	Ph.D.	The Pennsylvania State University, University Park, PA Concentration: Clinical Psychology: Child Minor Concentration: Human Development and Family Studies Dissertation: The Sustained Impact of the Head Start REDI Intervention on Children's Executive Function Trajectories through Third Grade
2015-2016	Clinical Psychology Internship	University of Washington School of Medicine, Seattle, WA Clinical Internship in General Child Track
2012	M.S.	The Pennsylvania State University, University Park, PA Thesis: Children's Self-Regulation and Their Academic and Social-Emotional Adjustment to School: The Roles of Executive Function Skills, Attention Control, and Impulse Control
2009	B.A.	Major: Psychology Minor: English Brigham Young University, Provo, UT *Cum Laude*

Publications

Sasser, T. R., Beekman, C. R., & Bierman, K. L. (2014). Preschool executive functions, single-parent status, and school quality predict diverging trajectories of classroom inattention in elementary school. *Development and Psychopathology*, 1-13. doi: 10.1017/S0954579414000947

Sasser, T. R., Bierman, K. L., & Heinrichs, B. (2014). Executive functioning and school adjustment: The mediational role of pre-kindergarten learning-related behaviors. *Early Childhood Research Quarterly*. doi: 10.1016/j.ecresq.2014.09.001

Bierman, K. L., & **Sasser, T. R.**, (2014). Conduct Disorder. In M. Lewis & K. Rudolph (Eds.). *Handbook of Developmental Psychopathology, 3rd edition.* New York: Springer.