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Executive Functioning and School Adjustment: The Mediational Role of Pre-kindergarten Learning-related Behaviors

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Abstract

164 four-year-old children (14% Latino American, 30% African American, 56% European American; 57% girls) in 22 Head Start classrooms were followed through third grade. Growth curve models were used to estimate the predictive associations between pre-kindergarten executive function (EF) skills and trajectories of academic skill development (math, literacy, overall academic functioning) and social-emotional adjustment at school (social competence, aggression), controlling for child sex, race, verbal IQ, and pre-kindergarten baseline scores. Direct developmental pathways were examined, along with indirect pathways, in which the association between preschool EF and elementary school adjustment was mediated by classroom learning behaviors. Preschool EF significantly predicted later math skills, academic functioning, and social competence, and marginally predicted later literacy skills. Preschool learning behaviors fully mediated the association between EF and later literacy skills and social competence, but did not mediate associations between EF and later math skills or academic functioning. Implications for developmental theory and early education are discussed.

Children growing up in poverty are particularly likely to show delays in preschool cognitive and social-emotional development, contributing to a gap in school readiness that predicts long-term disparities in educational outcomes (Blair, 2002; Ryan, Fauth, & Brooks-Gunn, 2006). Recent research focused on the developmental roots of school readiness has highlighted the role that executive function (EF) skills play in helping children adjust to and learn effectively in school settings (Blair & Diamond, 2008; Raver, 2012). EF involves higher-order cognitive regulatory processes, including working memory, inhibitory control, and attention set-shifting skills, that enhance children's capacities for sustained goal-oriented exploration and problem-solving (Carlson, 2005). Conceptually, EF skills help children succeed academically by facilitating concept learning and reasoning, and they may also help children succeed socially, by supporting emotion regulation, interpersonal cooperation, and aggression control (Zelazo, Carlson, & Kesek, 2008). EF skills are moderately correlated with teacher ratings of engaged learning behaviors and may have their effect on school success, at least in part, by fostering child "on task" participation and learning efforts in the classroom (Brock, Rimm-Kaufman, Nathanson, & Grim, 2009)

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In recent years, developmental research on preschool EF skills has proliferated, spurred especially by the hope that understanding and facilitating these skills might enhance school readiness among children at-risk (Hughes, 2011). Yet, an unresolved question involves the degree to which preschool EF skills predict the school adjustment of socio-economically disadvantaged children beyond the initial transition into elementary school across the dual domains of academic and social-emotional functioning. An additional question involves the nature of this association, and the degree to which links between EF skills and later school success are direct or indirect, mediated by classroom learning behaviors. The present study addressed these two issues by: 1) examining links between preschool EF and trajectories of both academic skills (math achievement, reading achievement, academic functioning) and social-emotional adjustment (social competence, aggression) through third grade, and 2) determining the degree to which links between preschool EF and later academic and social-emotional outcomes were mediated by classroom learning behaviors.

Executive Function Skills

Cognitive-developmental neuroscience research has documented the rapid development of EF skills during the preschool years and their positive associations with emergent numeracy and literacy skill acquisition (Hughes, 2011). EF skills are typically measured using standardized challenges designed to tax cognitive regulation under conditions of novel problem-solving (Carlson, 2005). For example, on the Peg Tapping [PT] task (Diamond & Taylor, 1996), children must inhibit the impulse to imitate the examiner and instead tap twice when the interviewer taps once, or tap once when the interviewer taps twice. On the Dimensional Change Card Sort [DCCS] (Frye, Zelazo, & Palfai, 1995) children sort cards by shape (or color) and then switch and sort by the other dimension. PT and DCCS both require attention control under conditions of cognitive conflict, exercising working memory to hold the rule in mind, inhibitory control to resist the prepotent response, and attention set-shifting to re-focus attention on the alternative goal. Longitudinal studies document prediction from these kinds of preschool EF tasks to achievement after the transition into elementary school. For example, in one study, attention set-shifting and inhibitory control measured in preschool predicted math skills and literacy skills at the end of kindergarten (Blair & Razza, 2007). In other studies, preschool EF skills predicted math achievement at age 6 (Clark, Pritchard, & Woodward, 2010) and predicted growth in children's math and reading skills over the first three years of primary school (Bull, Espy, & Wiebe, 2008). EF skills measured at school entry (start of the kindergarten year) similarly predicted math and literacy skills at the end of the kindergarten year (McClelland et al., 2007), and also predicted math achievement two years later, after controlling for baseline math skills (Mazzocco & Kover, 2007; Morrison, Ponitz, & McClelland, 2010).

Although less studied, preschool EF skills have also been linked with social-emotional adjustment. Conceptually, EF skills may function as "top down" cognitive regulatory processes that moderate "bottom up" reactive impulses and emotions, facilitating the child's capacity to manage emotional arousal, delay behavioral responding, and exert volitional control, thereby fostering social collaboration and aggression control (Blair, 2002; Rothbart, 2004). Concurrent links between preschool EF skills and social-emotional adjustment (social competence and aggression) have been documented (Bierman, Torres, Domitrovich, Welsh,

& Gest, 2009). In addition, studies have demonstrated predictive links between EF skills in the early elementary grades and social competence one year later (Ciariano, Visu-Petra, & Settanni, 2007), as well as social competence and reduced externalizing behaviors two years later, controlling for baseline behaviors (Riggs, Blair, & Greenberg, 2004). However, evidence linking preschool EF with elementary school social-emotional adjustment is still needed.

One contribution of the present study was to examine the predictive links between preschool EF skills and trajectories of elementary school adjustment through third grade in both academic and social-emotional domains. It was hypothesized that preschool EF skills may support academic achievement and social-emotional adjustment directly, by providing the cognitive regulation that allows children to perform more complex mental operations and thereby solve more complicated problems. In addition, an indirect pathway was explored, based on the hypothesis that EF skills may enhance children's productive learning behaviors at school, thereby indirectly supporting positive academic and social outcomes by fostering a higher level of "on task" classroom learning.

Classroom Learning Behaviors

In education research, productive learning behaviors are conceptualized as the proximal gateway to learning. The basic premise is that children who can draw on self-regulatory capacities to exert "on task" learning behavior have higher levels of exposure to instructional content and more opportunities to practice new skills and receive corrective feedback than their more distractible, off-task peers, thereby experiencing faster and greater cumulative learning (Fantuzzo, Perry, & McDermott, 2004; Fuchs et al., 2005). Research has shown that children who apply themselves more productively in the classroom, showing higher motivation for learning, greater persistence on challenging tasks, and more conscientious work habits experience enhanced academic progress and social adjustment (Fantuzzo, Perry, & McDermott, 2004; Ladd & Dinella, 2009; Li-Grining, Votruba-Drzal, Maldonado-Carreño, & Haas, 2010). For example, analyses of the Early Childhood Longitudinal Study – Kindergarten Cohort (ECLS-K) demonstrated significant links between adaptive learning behaviors in kindergarten, and reading and math achievement in the later elementary years (Bodovski & Farkas, 2007; Li-Grining et al., 2010). Similarly, in another sample, McClelland, Acock, and Morrison (2006) found that teacher ratings of children's kindergarten learning behavior predicted growth in literacy and math from kindergarten to second grade, and predicted reading and math achievement in sixth grade. Examining bi-directional influences from first through fifth grade, Stipek, Newton, and Chudgar (2010) confirmed that learning behaviors in one grade predicted literacy achievement in the subsequent grade in which it was assessed, but literacy skills did not predict subsequent learning-related behaviors.

Teacher ratings of attention problems in the classroom are closely related (inversely) to teacher-ratings of adaptive learning behaviors, with items that focus on elevated distractibility, difficulties sustaining attention, poor concentration, and difficulty completing tasks, and they are significantly associated with underachievement and behavior problems at school (Spira & Fischel, 2005). For example, in several large, longitudinal studies, teacher

ratings of attention problems in kindergarten or first grade predicted reduced academic achievement in later years, with early achievement and cognitive ability controlled (Breslau et al.,2009; Duncan et al., 2007). In preschool, significant correlations link attention problems with delayed emergent literacy skills (Lonigan et al., 1999) and, among children with ADHD, teacher-rated attention problems during preschool predict reduced achievement after the transition into elementary school (Spira & Fischel, 2005).

Preschoolers who exhibit adaptive learning behaviors in preschool typically also show positive social behavior, good peer relations, and low levels of aggressive-disruptive behavior (Coolahan, Fantuzzo, Mendez, & McDermott, 2000; Fantuzzo, Perry, & McDermott, 2004; Ladd & Dinella, 2009), and conversely elevated attention problems in preschool are associated with peer difficulties and heightened aggression (Spira & Fischel, 2005). The extent to which adaptive learning behaviors in preschool predict to positive social-emotional outcomes after the transition into elementary school has not yet been studied.

EF Skills, Classroom Learning Behaviors, and Possible Mediation of Effects

EF tasks are designed to assess children's higher-order cognitive performance under affectively-neutral and standardized conditions. In contrast, teacher ratings of classroom learning behaviors reflect children's self-regulation performance under the multi-tasking and emotionally arousing context of the classroom, and hence reflect motivation and emotion regulation, as well as cognitive skills. Hence, although conceptually linked and moderately inter-correlated, EF tasks and teacher ratings of learning behaviors may each make independent contributions to later academic achievement and social-emotional school adjustment (Blair, 2002; Clark et al., 2010).

Developmentally, EF skills may underlie and predict adaptive learning behaviors (Blair, 2002). For example, EF skills measured at the start of the year predict teacher ratings of adaptive learning behaviors at the end of the year in preschool (Denham, Warren-Khot, Bassett, Wyatt & Perna, 2012) and kindergarten (Ponitz, McClelland, Matthews, & Morrison, 2009). Similarly, Brock et al (2009) found that EF skills measured in the fall of kindergarten predicted observer-rated learning behaviors and teacher-rated self-directed learning at the end of kindergarten, with cognitive ability controlled. These findings suggest a predictive link between EF and adaptive learning behaviors. Classroom learning behaviors, in turn, may promote later achievement and social-emotional adjustment at school, and may add to or possibly mediate the impact of EF skills on school success. Only limited research is available to address the degree to which adaptive learning behaviors may mediate the association between EF skills and school adjustment. Studying preschool children attending Head Start, Blair and Razza (2007) found that EF skills and teacher ratings of preschool learning behaviors each uniquely predicted kindergarten math skills, but they did not formally test for mediation. Similarly, Brock et al. (2009) found that EF skills at the start of the kindergarten year predicted both math achievement and classroom learning behavior at the end of the year, but found no evidence for mediation. These studies suggest that EF skills and classroom learning behaviors may affect achievement independently, with the former providing an index of higher-order cognitive processes that enhance concept acquisition and

problem-solving, and the latter tapping motivation and behavioral regulation skills that foster "on task" and focused learning efforts (Blair & Razza, 2007). However, more research is needed to address this issue, including longitudinal studies that examine multiple domains of elementary school adjustment predicted from preschool EF skills and classroom learning behaviors. In particular, research is needed to determine whether preschool EF is associated with social-emotional adjustment in elementary school in ways that are similar to or different from its association with academic achievement.

The Present Study

The present study used measures of preschool EF and classroom learning behaviors to predict trajectories of elementary school adjustment in the two broad domains of academic skills (math achievement, reading achievement, academic functioning) and social-emotional adjustment (social competence, aggression) through third grade. It was hypothesized that preschool EF and learning behaviors would each account for unique variance in each of the elementary outcomes. In addition, the present study tested mediation models to determine the degree to which preschool learning behaviors accounted for links between preschool EF and later elementary school outcomes. It was hypothesized that preschool learning behaviors would mediate, at least partially, the association between preschool EF and later elementary school academic achievement and social-emotional adjustment.

Method

Participants

Participants included 164 children (14% Latino American, 30% African American, 56% European American; 57% girls) in 22 Head Start classrooms located in three Pennsylvanian counties who comprised the "usual practice" control condition in a preschool intervention study (reference blinded). At the beginning of the Head Start year, children were, on average, 4.49 years old (SD = 0.31; range: 3.72–5.62). Their families met the requirements for participation in Head Start; 68% had incomes below the national poverty level, with an average income-to-needs ratio of .88, indicating that many families were financially stressed. In terms of education, 33% of the parents had not completed high school and most of the others (65%) had graduated from high school or attained a GED, often with some additional technical training; only 2% had a college degree. According to the Hollingshead (1975) classification system, 79% of the families fell into the unskilled or semi-skilled labor categories. Forty-three percent were single-parents.

Procedures

At the beginning of the Head Start year, brochures describing the study were distributed to parents of all four-year-old children in participating classrooms, and 86% elected to participate and completed initial assessments. Informed consent was obtained from parents during the initial home visit assessment, and parents renewed their consent each year. Children were followed over the Head Start year and into elementary school, with some data collected for 94% of the original sample in kindergarten (N = 154) and first grade (N = 154), 90% in second grade (N = 148), and 85% in third grade (N = 140).

In the fall and spring of the Head Start year, as well as the spring of each subsequent year kindergarten through third grade, trained research assistants visited schools and conducted child assessments during individual "pull-out" sessions. The research assistants also delivered and explained the rating forms to teachers, who completed them on their own time and returned them to the project. Children received small prizes and teachers were compensated financially for completing ratings. All study procedures were approved by the university IRB and were in compliance with the standards for ethical research established by the American Psychological Association.

Measures

The predictor variables used in this study included EF skills (assessed directly) and classroom learning behaviors (rated by teachers) in the fall of pre-kindergarten. The outcomes included direct assessments of reading and math skills, and teacher ratings of academic functioning, social competence, and aggression collected annually from spring of pre-kindergarten through third grade.

Predictors—EF skills were assessed with two tasks administered directly to children in the fall of the pre-kindergarten year. On the *Peg Tapping* task (Diamond & Taylor, 1996) children were asked to tap a pencil twice when the experimenter tapped once, and to tap once when the experimenter tapped twice. After 6 practice trials, child were administered 16 mixed one-tap and two-tap trials; their score was the total number of correct responses out of the 16 trials ($\alpha = .86$). On the *Dimensional Change Card Sort* (DCCS; Frye, Zelazo, & Palfai, 1995), children were presented with cards that varied in color (blue and red) and shape (rabbits and boats). Children were first taught to sort the cards according to one dimension (color or shape) and were then asked to switch and sort the cards based on the other dimension, thereby testing their attention set-shifting and inhibitory control skills; their score was the number of correct responses on six trials after the switch ($\alpha = .93$). Scores on Peg Tapping and DCCS were significantly correlated ($r = .25$, $p < .01$), and they were standardized and averaged to create a composite EF score.

Pre-kindergarten lead and assistant teachers rated children's learning behaviors in the classroom using two scales. *Classroom Participation,* drawn from a school readiness inventory developed for the larger project, included 8-items tapping self-regulation, learning motivation, and conscientiousness (e.g., "This child can follow the rules and routines that are part of the school day," "This child seems enthusiastic about learning new things," "This child is able and willing to follow teacher instructions," "This child is careful with his or her work;" $\alpha = .95$). Items were rated on a six-point Likert-type scale (1 = strongly disagree to 6 = strongly agree); the average item score was used in analyses. In addition, teachers completed the *ADHD Rating Scale* (DuPaul et al., 1997), which included an 8-item sub-scale reflecting attention problems in the classroom (e.g., "Is easily distracted," "Has trouble staying focused," "Doesn't seem to listen;" $\alpha = .95$). Each item was rated on a four-point Likert-type scale (0 = not at all to 3 = very much). Scores on these two scales were highly correlated ($r = -.82$). The inattention scale was reverse coded, each scale score was standardized, and they were averaged to form a total score reflecting children's learning behaviors in the pre-kindergarten classroom context.

Academic outcomes—Outcome measures were collected annually in the spring of each year, from pre-kindergarten through third grade. The *Applied Problems* scale of the Woodcock-Johnson III Tests of Achievement (Woodcock, McGrew, & Mather, 2001) assessed math skills at each time point. Initial items assessed understanding of numbers (e.g., showing two fingers, counting objects) and more advanced items required computation (e.g., adding or subtracting). Following standardized administration procedures, children were presented with questions in order of increasing difficulty until they reached a criterion of inaccurate responses, when the test was discontinued (α = .79). Children's total scores were used in this study, re-standardized within the sample for growth modeling.

Because children's literacy skills develop rapidly during the preschool and early school years, several different measures were used over the course of the study. In pre-kindergarten, emergent literacy skills were assessed with three sub-tests from the *Test of Preschool Early Literacy* (TOPEL; previously Pre-CTOPP; Lonigan, Wagner, Torgesen, & Rashotte, 2007). These assessed phonological awareness, including the capacity to combine different sounds to form words (*Blending,* 18 items, α = .84), and the capacity to deconstruct words into separate sounds (*Elision*, 21 items, α = .80). In addition, on the *Print Awareness* subtest, children identified pictures of letters and named letters (36 items; α = .96). These scales were significantly inter-correlated (r = .31 to .47) and were standardized within the sample and composited. In kindergarten through grade 2, literacy skills (letter knowledge, word decoding skills, and sight words) were assessed with the *Letter-Word Identification* subtest of the Woodcock-Johnson III Tests of Achievement (Woodcock et al., 2001; α = .89). In addition, the Test of Word Reading Efficiency [TOWRE] (Torgensen, Wagner, & Rashotte, 1999) was administered to tap speed of processing. On this test, children read as many sight words (Sight Word Efficiency) as they could in 45 seconds; they then sounded out as many phonemic non-words (Phonemic Decoding Efficiency) as they could in 45 seconds. Their score was the total number of words read accurately. Children's raw scores on these measures were inter-correlated (r *s* ranged from .50-.87 in preschool, .77–.90 in first grade, and .81–.85 in second grade). Measures of literacy skills at each time point were standardized and averaged to form a composite score representing literacy skills at each grade level. In third grade, the Letter-Word Identification scale was not administered, so literacy skills were estimated with a composite of the two sub-tests of the TOWRE (r = .79).

Overall academic functioning was assessed using teacher ratings. At the end of each academic year beginning in kindergarten, teachers completed a 3-item *Academic Performance Scale* developed for the larger project, which required teachers to rate the child's skills in areas of reading, writing, and math (1 = near the very bottom of your class to 5 = near the very top of your class, α = .95). In addition, in second and third grades, teachers also completed the 9-item *Academic Success* subscale of the Academic Performance Rating Scale (DuPaul & Rapport, 1991). On these items, teachers rated the accuracy of the child's language arts and math work during the past week, and the overall quality of the child's skills in reading, writing, math, and general academics (1 = poor to 5 = excellent; α = .93). These two scales were standardized and averaged to form a composite score of teacher-rated academic functioning.

Social competence and aggression—Teacher ratings were also used to assess children's social competence and aggressive-oppositional behavior problems at each time point. The 13 items of the *Social Competence Scale* (Conduct Problems Prevention Research Group [CPPRG], 2003) were rated on a six-point Likert-type scale (0 = never to 5 = always), and included prosocial behaviors such as sharing, helping, understanding other's feelings, as well as self-regulatory behaviors, such as resolving peer problems independently. The ratings of lead and assistant teachers in pre-kindergarten were averaged (r = .65; α = .95).

Seven items from the *Teacher Observation of Child Adaptation – Revised* (TOCA – R; Werthamer-Larsson, Kellam, & Wheeler, 1991) assessed overt aggression (e.g., stubborn, yells, fights) each year. Items were rated on a six-point Likert scale (0 = never to 5 = always). Ratings provided by lead and assistant teachers in pre-kindergarten were averaged (r = .71; α = .91).

Control variables—The Expressive One-Word Picture Vocabulary Test (EOWPVT: Brownell, 2000) was administered in the fall of pre-kindergarten and served as a proxy control for verbal IQ. On this measure, children were asked to give the word that best described pictures they were shown (α = .93). All growth model analyses included the EOWPVT as a baseline covariate, along with the baseline score on the outcome measure being analyzed. Baseline teacher ratings were problematic as a covariate, because the same pre-kindergarten teacher completed ratings in the fall (baseline) and spring of pre-kindergarten (first time point used in growth models), whereas all subsequent teacher ratings were completed by different and independent teachers. To avoid using the same teacher's assessment for these two time points, parent ratings of social competence and aggression were used as the baseline covariates for growth curves modeling teacher-rated social competence and aggression, and teacher ratings of children's language skills were used as the baseline covariate for growth curves modeling teacher-rated academic functioning.

Results

Table 1 presents descriptive statistics for the baseline variables assessed at the fall of the pre-kindergarten year. Table 2 presents the means and standard deviations of the measures used as outcomes in the growth model, from the spring of the pre-kindergarten year through third grade. Although raw scores are presented for each measure separately in the table, standardized scores of the composites were used in all analyses. The standardization does not affect statistical tests, but it establishes a common scale for the metrics across measures and provides guidance for interpreting the magnitude of effects. It is worth noting that, because measures of each outcome were standardized, the assessments of change do not reflect absolute levels of change in adjustment outcomes over time, but rather the relative status of each child compared to other children within the sample.

In Table 3, simple correlations between EF skills, learning behaviors, and composite outcome scores measured in pre-kindergarten and third grade. Several associations are worth noting. EF skills and teacher-rated learning behaviors measured at the start of the pre-kindergarten year were moderately inter-correlated (r = .42) and demonstrated similar as

well as differential associations with later academic and social behavioral outcomes. Pre-kindergarten EF skills significantly predicted all three measures of academic functioning (math, literacy, and teacher-rated academic functioning) at the end of the pre-kindergarten year and in third grade. The magnitude of the predictive correlations was similar at each time point for math skills (r = .41 pre-kindergarten; r = .41third grade) and for academic functioning (r = .41 pre-kindergarten; r = .39 third grade), but declined over time for literacy skills (r = .58 pre-kindergarten; r = .28 third grade). Pre-kindergarten fall EF skills significantly predicted pre-kindergarten spring social behavior (r = .33 social competence; r = −.18 aggression), but not third grade social behavior (r = .08 social competence; r = −.05 aggression). Teacher-rated learning behaviors in the fall of pre-kindergarten also significantly predicted academic skills in the spring of pre-kindergarten and in third grade, although the magnitude of these correlations was smaller than for EF, with predictive associations for math (r = .24 pre-kindergarten; r = .25 third grade), literacy (r = .39 pre-kindergarten; r = .36 third grade), and academic functioning (r = .43 pre-kindergarten; r = . 29 third grade). Pre-kindergarten learning behaviors also significantly predicted social behavior at both time points, although the magnitude of the prediction was greater for the spring of pre-kindergarten than for third grade, with predictive associations for social competence (r = .67 pre-kindergarten; r = .31 third grade) and for aggression (r = -.63 pre-kindergarten; r = -.27 third grade). Each of the outcomes was significantly and moderately stable from the end of pre-kindergarten through third grade, with stability correlations ranging from r = .32 (for aggression) to r = .54 (for math skills). Finally, despite the shared method variance associated with teacher ratings of children's academic functioning and teacher ratings of children's social behavior, teacher ratings of academic functioning were more highly associated with direct tests of math and literacy skills within each time point and across time, demonstrating concurrent and discriminant validity.

Plan of Analysis

Separate hierarchical linear models were run for each of the three academic outcomes (literacy skills, math skills, and teacher-rated academic functioning) and the two social behavior outcomes (social competence, aggression). In each case, an initial model tested the hypothesis that children's EF skills measured in the fall of the pre-kindergarten year would predict their elementary school outcomes, controlling for baseline skills and verbal IQ and other study covariates including sex, race, and county site. Linear growth models were estimated in SAS 9.2 using PROC MIXED. Children's scores, standardized by year, over the five spring outcome assessments (spring of pre-kindergarten through third grade) were modeled to represent their relative adjustment over time as they transitioned into elementary school and traversed the early grades. The effect of time on the slope of adjustment from the spring of pre-kindergarten through third grade was estimated at Level 1. Children's EF skills at the fall of pre-kindergarten were included at Level 2 as a predictor of the Level 1 coefficients (intercept and slope). Covariates were also included at Level 2. Initial models included quadratic and cubic effects of time, but because these were nonsignificant for change for each adjustment outcome, only linear growth is specified in the final models.

A second set of hierarchical linear models tested the hypothesis that the association between children's EF skills and their elementary school outcomes would be mediated, at least

partially, by their classroom learning behaviors. To test this hypothesis, teacher-rated learning behaviors in the fall of pre-kindergarten was added as a Level 2 predictor in the models described above. Procedures recommended by Krull and MacKinnon (2001) were applied to test for multilevel mediation, and RMediation (Tofighi & MacKinnon, 2011) was used to assess the statistical significance of mediated effects.

Predicting Academic Outcomes

Results from the hierarchical models examining academic outcomes are presented in Table 4. Effects for literacy skills are shown in the top panel of the table, with the model including EF skills on the left, and the model including both EF skills and learning behaviors as concurrent predictors on the right. With children's baseline literacy scores and verbal IQ in the model, the prediction from baseline EF skills to the child's average level of literacy skills over time was marginally significant, $\beta = .12$, $p = .059$, indicating that with each standard deviation increase in children's EF skills at baseline, their literacy skills increased, on average, by about one-tenth of a standard deviation. The effect for time was non-significant, as was the interaction between EF skills and time, suggesting that EF skills affected the level but not the pace or slope of literacy skill acquisition. When baseline learning behaviors were added to this model, they emerged as a significant predictor of literacy skill levels, $\beta = .18$, $p = .005$. Effects for time and interactions between time and learning behaviors were non-significant. With learning behaviors in the model, the effect for EF was reduced to non-significance, $\beta = .07$, $p = .33$. To test for multilevel mediation, the estimates of the association between baseline EF skills and later literacy without (model 1) and with (model 2) learning behaviors in the model were compared (Krull & MacKinnon, 2001). RMediation (Tofighi & MacKinnon, 2011) indicated that the mediated effect was statistically significant, $p < .05$.

Results for children's math skills are shown in the middle panel of Table 4. With children's baseline math scores and verbal IQ in the model, the prediction from baseline EF skills to the child's average level of math skills over time was statistically significant, $\beta = .26$, $p < .001$, indicating that with each standard deviation increase in children's EF skill at baseline, their math skills increased, on average, by about one-quarter of a standard deviation. The effect for time was non-significant, as was the interaction between EF skills and time, suggesting that EF skills affected the level but not the pace or slope of math skill acquisition. When baseline learning behaviors were added to this model (right hand column), they emerged as a marginally significant predictor of literacy skill levels, $\beta = .11$, $p = .06$. Effects for time and time by learning behaviors were non-significant. With learning behaviors in the model, the effect for EF was reduced to $\beta = .23$, $p < .001$. RMediation (Tofighi & MacKinnon, 2011) indicated that the mediated effect was not statistically significant.

The bottom panel in Table 4 shows the results for models examining teacher-rated academic functioning from pre-kindergarten through third grade. Baseline EF skills significantly predicted later classroom academic functioning, $\beta = .19$, $p < .01$, indicating that with each standard deviation increase in EF skill at the fall of pre-kindergarten, children's teacher-rated academic functioning increased, on average, by about one-fifth standard deviation. The effect of time was not significant, nor was the time by EF interaction. In the second model,

classroom learning behaviors were added and emerged as a marginally-significant predictor of teacher-rated academic functioning, β = .14, $p = .06$. The learning behaviors by time interaction was not significant. With learning behaviors in the model, the predictive association of EF skills was reduced to β = .16, but was still statistically significant, $p = .03$. The mediated effect was not statistically significant, $p < .10$.

Predicting Social Behavior Outcomes

Next, models were estimated predicting teacher-rated social behaviors over the transition to school and during the early school years. Results are presented in Table 5. Effects for social competence are shown in the top panel of the table. On the left, the results of model 1 revealed that the prediction from baseline EF skills to the child's average level of social competence over time was statistically significant, β = .13, $p = .04$, indicating that with each standard deviation increase in children's EF skill at baseline, their social competence increased, on average, by one-eighth of a standard deviation. The effect for time was non-significant, as was the interaction between EF skills and time, suggesting that EF skills affected the level but not the slope of social competence. When baseline learning behaviors were added to this model (model 2 on the right), they emerged as a significant predictor of social competence, β = .49, $p < .001$. Effects for time and interactions between time and learning behaviors were non-significant. With learning behaviors added, the EF effect was reduced to non-significance, β = −.01. RMediation (Tofighi & MacKinnon, 2011) indicated that the mediated effect was statistically significant, $p < .05$.

Finally, the lower panel in Table 5 shows the model predicting children's aggression. In model 1, baseline EF skills were not significantly associated with the child's average level of aggression over time, β = −.03. The effect for time was non-significant, as was the interaction between EF skills and time. When baseline learning behaviors were added to this model, they emerged as a significant predictor of reduced aggression, β = −.49, $p < .001$, indicating that with each standard deviation increase in children's adaptive learning behaviors at baseline, their aggression decreased by half of a standard deviation. Given the non-significant association between EF and aggression, mediation was not assessed.

Discussion

The present study examined predictive links between EF skills measured in the fall of the pre-kindergarten year and trajectories of elementary school outcomes through third grade in a sample of children growing up in poverty. Whereas pre-kindergarten EF significantly predicted later math skills and teacher-rated academic functioning in a direct pathway, EF skills only marginally predicted later literacy skills, and this pathway was fully mediated by pre-kindergarten learning behaviors. Pre-kindergarten EF skills also significantly predicted later social competence, in a pathway that was fully mediated by learning behaviors. EF skills did not predict later aggression, although pre-kindergarten learning behaviors did. These differential patterns of association are discussed below.

Predicting Academic Outcomes

Simple correlations revealed significant associations that remained moderate to strong from preschool EF to third grade assessments of math achievement and teacher-rated academic functioning (r = .41 and .39, respectively). In growth models examining trajectories of academic performance through third grade, which controlled for baseline scores and verbal IQ, preschool EF significantly predicted math achievement and teacher-rated academic functioning. Preschool learning engagement accounted for a small amount of shared variance in these models, but only slightly diminished the associations with EF skills (from β = .26 to β = .23 for math, and from β = .19 to β = .16 for academic functioning), which did not constitute a statistically significant level of mediation. In contrast, for literacy skills, the magnitude of the correlation with EF skills was strong from fall to spring within the pre-kindergarten year (r = .58), but only moderate from pre-kindergarten to third grade (r = .28). Preschool EF was only marginally predictive of literacy skills in the growth models (β = .12, p = .059), and this effect was fully mediated by preschool learning behaviors.

These findings are in alignment with other studies that have documented links between preschool or kindergarten EF skills and later math achievement (Blair & Razza, 2007; Brock et al., 2009; Bull & Scerif, 2001; Ponitz et al., 2009), and they extend the documented longitudinal scope of the associations. Links between early EF and math achievement were stronger than between early EF and literacy, replicating two prior studies (Blair & Razza, 2007; Ponitz et al., 2009). To account for these differences, Blair and Razza (2007) hypothesized that the computational and problem-solving elements of math utilize EF skills more heavily than do the decoding skills associated with early literacy. This interpretation is consistent with education research on students who experience difficulties with math. For example, Swanson (2006) found that inhibitory control of attention played a particularly important role in predicting child computational abilities. Similarly, Passolunghi and Pazzaglia (2005) found deficits in working memory and inhibitory control among children who were poor math problem-solvers, as they remembered less relevant information than more skilled problem solvers, and more often experienced the intrusion of irrelevant information into their thinking. Consistent with these studies, in a short-term longitudinal study, it was the combination of working memory deficits and inattention that best predicted the emergence of computational and problem-solving math difficulties over the course of the first-grade year (Fuchs et al., 2005).

The present findings, like those of Blair and Razza (2007) suggest that EF skills may be significantly associated with literacy skill acquisition in pre-kindergarten, but this association diminishes over time. Two different factors may help explain why EF skills were less strongly associated with trajectories of literacy skills than math or overall academic functioning in this study. First, this pattern of effects is consistent with the conceptualization that EF skills are called upon for novel problem-solving (Hughes, 2011). When children are first learning to recognize letters and sounds, and sounding out words, working memory and inhibitory control may play a critical role in their task performance. However, with repeated practice, letter and word knowledge may become increasingly automatic, thereby decreasing the utilization of EF skills for the processing of letter and word identification (Blair & Razza, 2007). If more novel reading skills had been evaluated, such as those tapping

comprehension and reasoning, perhaps EF skills would have played a stronger predictive role. Second, Brock et al. (2009) noted that literacy skills are a much more intensive focus of classroom instruction than are math skills in kindergarten and the early elementary years, which may reduce the impact of individual differences in cognitive ability on skill acquisition. In particular, kindergartens have become increasingly focused on literacy instruction, with state standards typically including letter and letter-sound knowledge, as well as sight word recognition and basic phonetic decoding skills as kindergarten learning goals (Bryant, Clifford, & Peisner, 1991). High levels of instructional focus on literacy skills in kindergarten and first grade may compensate for low EF skills, by giving struggling students the additional learning and practice opportunities needed to master these skills. When children who are provided with sufficient instruction in letter and word knowledge and sufficient opportunity for practice, they may move toward automaticity, even if their EF skills are lower than those of their peers. Perhaps for this reason, classroom learning behaviors, which taps the child's motivation and utilization of classroom instruction and practice opportunities, emerged as the mediator between early EF and later literacy skill acquisition in this study.

Predicting Social-Emotional Outcomes

A unique feature of this study was the concurrent examination of trajectories of social-emotional adjustment in elementary school, as well as academic achievement. Conceptually, EF should promote social competence and enhance aggression control, but longitudinal studies have not yet examined these associations over the transition from preschool into the early elementary grades. In this study, preschool EF predicted trajectories of social competence through third grade, and this association was fully mediated by preschool classroom learning behaviors. Associations between EF skills and social-emotional school adjustment were expected, based on the extensive inter-connections between the developing prefrontal cortex that supports EF and the ventral medial frontal and limbic brain structures associated with emotional reactivity and regulation (Derryberry & Rothbart, 1997). Given these connections, developing EF skills are thought to increase the child's capacity to modulate – amplify or inhibit – these emotional arousal systems, thereby fostering emotion regulation and impulse control during the preschool years (Rueda, Posner & Rothbart, 2005). The preschool years represent an important developmental period for emerging social competence, as it is during preschool that children typically experience their first friendships and acquire the basic social and communication skills that allow them to cooperate effectively and coordinate their activities and efforts (Bierman et al., 2009). Inhibitory control, the ability to focus and shift attention, and emotion regulation skills each play central roles in promoting the capacity for productive social coordination, as they support emotional understanding, play planning and sequencing, rule-governed behavior, and interpersonal problem-solving (Blair & Diamond, 2008). Interestingly, however, classroom learning behaviors fully mediated the association between EF and social competence. By enabling more complex mental operations, EF skills may provide an important foundation of support for social participation and coordinated play. However, the EF tasks used here assess cognitive regulation in affectively neutral contexts, whereas social interaction is affectively arousing, and requires the multi-faceted regulation of behavior, emotion, and thought, in order to navigate social tasks such as resource sharing and conflict resolution. In this way,

the regulatory skills that support social competence may be more similar to those tapped by teacher-rated classroom learning behaviors, which reflect children's self-regulation performance in the classroom context, incorporating aspects of motivation and emotion regulation, as well as cognitive capacities (Blair, 2002; Clark et al., 2010).

Conceptually, the enhanced emotion regulation and inhibitory control skills associated with EF should also promote reductions in aggressive behavior, but in this study, the association between aggression and EF was not significant. Similarly, in a prior study comparing "hard to manage" 4-year-olds with normative peers, Brophy, Taylor and Hughes (2002) found no associations between EF tasks measuring set-shifting or working memory skills and problem behaviors, although the "hard to manage" children were less compliant and showed more perseveration errors on the EF tasks. Several researchers have suggested that the control of behavioral impulsivity may have different neural roots that the regulation and inhibitory control of attention measured by the EF tasks used in this study (White et al., 1994). Consistent with this perspective, EF tasks that require attention inhibition and set-shifting have factored separately from tasks that require behavior inhibition in some studies, and have shown differential associations with other aspects of child functioning such as theory of mind (Blair & Razza, 2007; Nigg, 2006). Some researchers have suggested that it is the need for emotion regulation that differentiates child performance on "cool EF" tasks such as Peg Tapping and DCCS from performance on other kinds of "hot EF" tasks that require behavior inhibition, such as delay of gratification tasks (Zelazo et al., 2008). It is possible that, had we included EF measures that more effectively tapped emotion regulation skills or behavioral impulse control, they might have predicted later aggression in a way that the "cool EF" used here did not.

In addition, social behavior (social competence and aggression) are each multiply-determined and affected by features of the classroom context that may have a strong proximal impact on the shaping of classroom behavior. Factors such as classroom organization, teacher-student interactions, peer characteristics, and the contingent responding of teachers and peers to individual children may all affect classroom behavior, in addition to child characteristics (Denham et al., 2012). This may also explain the stronger predictive association that emerged between classroom learning engagement and aggression, relative to the association between EF skills and aggression. Classroom learning engagement and aggression also shared the same method of assessment (e.g., teacher ratings); however two considerations suggest that something other than shared method variance accounts for the observed pattern of associations. First, trajectories of aggression were based on multiple teachers, not only the pre-kindergarten teacher who rated initial classroom engagement. Second, ratings of academic functioning were also completed by teachers, and yet these showed a closer association with initial EF skills than with initial teacher ratings of classroom engagement.

Limitations

A key limitation of the current study was the reliance on brief measures to represent each of the predictor and outcome constructs – particularly an issue for assessing early EF and literacy and math skills. A larger battery of age-appropriate tasks would allow for a more

complete and nuanced examination of the relationship between EF skills and academic outcomes. In addition, the sample included only children from low-income families, and hence, the results may not generalize to other populations. Finally, although the study utilized a longitudinal design, it cannot specify causal relationships, as it is possible that other processes beyond those controlled for in the current analyses contributed to the observed relationships.

Implications and Future Directions

While acknowledging these limitations, the study findings have implications for early childhood programs and practices, and suggest several directions for future research. Early intervention programs, such as Head Start, aim to reduce delays in school readiness associated with poverty, in order to promote future educational success and enhance long-term employment opportunities (Ryan, Fauth, & Brooks-Gunn, 2006). The findings from this study support and extend other recent research that suggests that EF skills support school readiness, by enhancing the complexity and flexibility of children's thinking and problem-solving skills, and by fostering social competence (Blair & Diamond, 2008; Raver, 2012). At the same time, the findings also suggest that adaptive learning behaviors are important for school success, and that a parallel focus on the promotion of EF and adaptive learning behaviors is warranted during the preschool years. There is still considerable debate about the optimal strategies for enhancing children's EF and adaptive learning behaviors during the preschool years (for reviews see Bierman & Torres, in press; Diamond & Lee, 2011), but increasingly EF skills are being assessed in preschool intervention studies to evaluate intervention effects (Blair & Diamond, 2008). Certainly the present findings support additional research of this kind. A better understanding of the developmental roots and sequelae of EF skills and adaptive learning behaviors, as well as knowledge about intervention approaches that support them, may strengthen current approaches to early childhood education and foster improved outcomes for children.

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Table 1

Descriptive Statistics for Time 1 Variables: EF Skills, Learning Engagement, Verbal IQ

	N	*M*	*SD*	*Min*	*Max*
EF Predictors					
Peg Tapping	161	7.75	(5.88)	0.00	16.00
DCCS	160	3.12	(2.36)	0.00	6.00
Learning Engagement Predictors					
Classroom Participation	164	4.92	(0.90)	2.25	6.00
Inattention	164	0.82	(0.72)	0.00	3.00
Baseline Covariates					
Verbal IQ (EOWPVT)	161	82.37	(13.53)	55.00	118.00
Applied Problems	161	93.36	(13.84)	46.00	134.00
Blending	161	11.52	(4.29)	2.00	20.00
Elision	161	7.71	(3.43)	0.00	17.00
Print Awareness	161	7.97	(8.31)	0.00	33.00
Academic Performance	164	1.98	(0.58)	0.00	3.32
Social Competence	161	3.96	(0.89)	1.69	5.88
Aggression	164	2.01	(0.95)	1.00	5.00

Table 2

Descriptive Statistics for Time 2–6 Outcomes: Variables Used in Growth Models

Measures	Time				
	Pre-K	K	Gr. 1	Gr. 2	Gr. 3
Math Skills					
Applied Problems[a]	97.21 (11.17)	99.16 (10.99)	100.56 (11.68)	101.51 (13.75)	100.89 (14.39)
Literacy Skills					
Blending	13.04 (4.30)	NA	NA	NA	NA
Elision	9.61 (3.58)	NA	NA	NA	NA
Print Awareness	16.49 (12.60)	30.91 (9.19)	NA	NA	NA
Letter-Word ID[a]	NA	105.5 (10.6)	104.6 (12.4)	99.9 (11.6)	NA
Sight Words[a]	NA	96.4 (6.70)	98.2 (11.84)	99.6 (14.69)	101.1 (13.91)
Decoding[a]	NA	99.9 (4.51)	96.5 (11.00)	96.4 (13.18)	96.9 (13.68)
Teacher-Rated Academic Functioning					
Acad. Performance	2.13 (0.55)	3.08 (1.02)	3.00 (0.98)	NA	NA
Academic Success	NA	NA	NA	3.10 (0.81)	2.99 (0.73)
Teacher-Rated Social Behavior					
Social Competence	3.98 (0.88)	4.02 (0.98)	4.04 (0.99)	4.03 (0.97)	4.08 (0.99)
Aggression	2.07 (0.89)	1.96 (0.83)	1.95 (0.85)	1.99 (0.91)	1.95 (0.85)

Note: Pre-K = Spring of the pre-kindergarten year; K = Kindergarten; Gr. 1 = first grade; Gr. 2 = second grade; Gr. 3 = third grade. Standard deviations are in parentheses.

[a] = Nationally norm

Table 3

Correlations Among Predictors and Outcome Variables at Beginning and End of Study

	1	2	3	4	5	6	7	8	9	10	11
Fall of Prekindergarten											
1. Executive Function											
2. Learning Engagement	.42										
Spring of Prekindergarten											
3. Math Skills	.41	.24									
4. Literacy Skills	.58	.39	.47								
5. Academic Functioning	.41	.43	.34	.53							
6. Social Competence	.33	.67	.19	.31	.34						
7. Aggression	−.18	−.63	−.10	−.18	−.14	−.81					
Spring of Grade 3											
8. Math Skills	.41	.25	.54	.57	.39	.19	−.10				
9. Literacy Skills	.28	.36	.41	.39	.41	.32	−.21	.59			
10. Academic Functioning	.39	.29	.49	.49	.40	.32	−.18	.65	.63		
11. Social Competence	.08	.31	.10	.09	.01	.34	−.36	.22	.25	.36	
12. Aggression	−.05	−.27	−.06	−.08	.04	−.23	.32	−.14	−.16	−.28	−.80

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

Table 4

Predicting Academic Skills Through 3rd Grade With Pre-K EF and Learning Behaviors

Outcomes	Predictive Models			
	Model 1: EF		Model 2: EF & Learning Behaviors	
	β	(SE)	β	(SE)
Literacy				
Intercept	−.18	(.11)	−.12	(.11)
Baseline	.31**	(.07)	.28**	(.07)
Verbal IQ	.24**	(.07)	.23**	(.06)
Time	.01	(.02)	.01	(.02)
EF Skills	.12+	(.07)	.07	(.07)
Learning Behaviors	–	–	.18**	(.06)
Math				
Intercept	−.02	(.11)	.02	.11
Baseline	.32**	(.06)	.31**	.06
Verbal IQ	.16**	(.06)	.15**	.06
Time	−.00	(.02)	−.00	.02
EF Skills	.26**	(.06)	.23**	.06
Learning Behaviors	–	–	.11+	.06
Teacher-Rated Academics				
Intercept	−.14	.15	−.11	.14
Baseline	.20**	.07	.15*	.07
Verbal IQ	.24**	.07	.24**	.07
Time	.01	.02	.01	.02
EF Skills	.19**	.07	.16*	.07
Learning Behaviors	-	-	.14+	.08

Note: Controls include baseline score, IQ, sex, race, and study site.

+ $p = .06$.

* $p < .05$.

** $p < .01$.

Table 5

Predicting Social Behavior Through 3rd Grade With Pre-K EF and Learning Behaviors

Outcomes	Predictive Models			
	Model 1: EF		Model 2: EF & Learning Engagement	
	β	(SE)	β	(SE)
Social Competence				
Intercept	−.16	(.14)	−.07	(.12)
Baseline	.06	(.06)	−.00	(.05)
Verbal IQ	.14*	(.07)	.09	(.06)
Time	.01	(.02)	.01	(.02)
EF Skills	.13*	(.07)	−.01	(.06)
Learning Behaviors	-	-	.49**	(.06)
Aggression				
Intercept	.04	(.14)	.01	(.12)
Baseline	.16**	(.06)	.10*	(.05)
Verbal IQ	−.09	(.07)	−.04	(.06)
Time	−.00	(.03)	−.00	(.02)
EF Skills	−.03	(.06)	.11	(.06)
Learning Behaviors	-	-	−.48**	(.06)

Note: Analyses control for baseline score on the adjustment outcome, verbal IQ, child sex and race, and study site.

+ $p = .06$.

* $p < .05$.

** $p < .01$.