2009-07-21

Executive Functions and Approaches to Learning: Relationships to School Readiness in Head Start Preschoolers

Virginia E. Vitiello
University of Miami, virginia.vitiello@gmail.com

UNIVERSITY OF MIAMI

EXECUTIVE FUNCTIONS AND APPROACHES TO LEARNING: RELATIONSHIPS TO SCHOOL READINESS IN HEAD START PRESCHOOLERS

By

Virginia E. Vitiello

A DISSERTATION

Submitted to the Faculty
of the University of Miami
in partial fulfillment of the requirements for
the degree of Doctor of Philosophy

Coral Gables, Florida

August 2009

UNIVERSITY OF MIAMI

A dissertation submitted in partial fulfillment of
the requirements for the degree of
Doctor of Philosophy

EXECUTIVE FUNCTIONS AND APPROACHES TO LEARNING:
RELATIONSHIPS TO SCHOOL READINESS IN HEAD START PRESCHOOLERS

Virginia E. Vitiello

Approved:

____
Daryl B. Greenfield, Ph.D.
Professor of Psychology

____
Terri A. Scandura, Ph.D.
Dean of the Graduate School

____
Daniel Messinger, Ph.D.
Professor of Psychology

____
Heather Henderson, Ph.D.
Professor of Psychology

____
Batya Elbaum, Ph.D.
Professor of Education

____
Matthias Siemer, Ph.D.
Professor of Psychology

VITIELLO, VIRGINIA E. (Ph.D., Psychology)
<u>Executive Functions and Approaches to Learning: Relationships to School Readiness in Head Start Preschoolers.</u> (August 2009)

Abstract of a dissertation at the University of Miami.

Dissertation supervised by Professor Daryl B. Greenfield.
No. of pages in text. (68)

The purpose of this study was to determine whether the effects of executive functions on school readiness outcomes were mediated by approaches to learning in Head Start preschoolers. Executive functions are cognitive skills, including inhibition, cognitive flexibility, and working memory, that are involved in learning as well as regulating behavior (Blair, Granger, & Razza, 2005; Espy, McDiarmid, Cwik, Stalets, Hamby, & Senn, 2004). Approaches to learning include important learning-to-learn skills such as persistence, initiative, and motivation (Fantuzzo, Perry, & McDermott, 2004). Based on previous literature, it was hypothesized that strong executive functions would support the development of positive approaches to learning, which in turn would lead to increased school readiness. To test this, data were collected on 179 four-year-old Head Start preschoolers. Children were assessed on executive functions (cognitive inhibition, cognitive flexibility, and working memory), approaches to learning (using both a teacher rating scale and a direct observation), school readiness, and verbal ability. Results indicated that approaches to learning partially mediated the relationship between executive functions and school readiness, providing support for the study's main hypothesis. Results are discussed in the context of preparing at-risk preschool children for success in school.

Acknowledgments

I would like to thank my committee chair, Daryl Greenfield, and my committee members – Heather Henderson, Daniel Messinger, Matthias Siemer, and Batya Elbaum – for their support and helpful comments throughout this project. I would also like to thank my labmates, Ximena Dominguez E., Ariela Greenberg, Michelle Maier, Janna Fuccillo, and Lizzy Bell for the great teamwork, support, and friendship that they provided me. I would have never gotten this project done without having such a great research lab working long hours together. Finally, I would like to thank my parents, Vanessa and Geoff, and Roberto for their patience and support for the past five years.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Introduction

For low-income children at risk for school failure, preschool provides an opportunity to acquire skills that can lead to later school success (Zigler & Finn-Stevenson, 2007). The Head Start program, a federally-funded preschool program for at-risk children, targets school readiness across multiple domains of development, including literacy, math, and approaches to learning (Title 45 Code of Federal Regulations, 2005). However, researchers and policy makers have long been concerned that the positive effects of public preschool, and Head Start in particular, diminish over time (Lee, Brooks-Gunn, Schnur, & Liaw, 1990). This fade-out effect, coupled with an increased emphasis on achievement standards and accountability, has led some Head Start programs to focus more intensely on improving children's academic skills (Stipek, 2006). Evidence suggests, though, that a heavy academic focus in preschool may be associated with poorer achievement in later schooling (Marcon, 2002).

While academic skills are an important part of school readiness, focusing on these skills should not come at the expense of other competencies (Stipek, 2006). Recent research indicates that domain-general skills, including executive functions and approaches to learning, are also critical to school readiness (Blair & Razza, 2007; McWayne, Fantuzzo, & McDermott, 2004). Rather than concentrating predominantly on academic skills, therefore, it is important to better understand the role of domain-general skills in increasing school readiness. To this end, the current study examined relationships between executive functions, approaches to learning, and school readiness in Head Start preschool children. This study had two primary purposes. The first was to determine whether executive functions significantly predicted approaches to learning in Head Start preschool children. The second was to test whether approaches to learning mediated the relationship between executive functions and school readiness.

Domain-General Skills

The term "domain-general skills" refers to child competencies that support learning and development across school readiness domains rather than being content-bound. Two sets of domain-general skills, executive functions and approaches to learning, have received increasing attention in recent years. Executive functions are cognitive skills involved in regulating goal-directed actions (Brocki & Bohlin, 2004). Approaches to learning are learning-related behaviors and attitudes, including motivation, self-direction, attention, and persistence (Kagan, Moore, & Bredekamp, 1995; McWayne et al., 2004). Research indicates that both of these skill sets positively predict school readiness across multiple domains, including math, literacy, and social-emotional development (Blair, Granger, & Razza, 2005; Espy, McDiarmid, Cwik, Stalets, Hamby, & Senn, 2004; Fantuzzo, Perry, & McDermott, 2004; Schaefer & McDermott, 1999). Furthermore, both executive functions and approaches to learning are believed to be malleable and may therefore be amenable to intervention (Greenberg, Kusché, Cook, & Quamma, 1995; Kagan et al., 1995).

Executive functions. Researchers have studied executive functions for decades, but applications to education have emerged only in the past 10 to 15 years. Relatively little research has examined executive functions in preschool children, especially at-risk preschoolers such as the children enrolled in Head Start. The importance of executive functions to learning, however, makes this a critical area for further study.

Executive functions include multiple cognitive processes, of which the most commonly studied are inhibition, cognitive flexibility, and working memory. Inhibition involves the ability to refrain from giving a prepotent, or dominant, response in favor of a sub-dominant response (Korkman, 2000). Cognitive flexibility refers to the ability to shift between two or more competing response alternatives (Davidson, Amso, Anderson, & Diamond, 2006). Working memory refers to the amount of information one can hold and manipulate in conscious thought (Hughes & Graham, 2002). Each of these components has been studied extensively in adult and child populations and has recently been linked to educational outcomes.

Evidence suggests that executive functions contribute to achievement across age groups. Multiple studies have shown that working memory, inhibition, and cognitive flexibility are related to math and literacy achievement in elementary-aged children (Bull & Scerif, 2001; Hooper, Swartz, Wakely, de Kruif, & Montgomery, 2002; Lee, Ng, Ng, & Lim, 2004; Mazzocco & Koyer, 2004; St. Claire-Thompson & Gathercole, 2006). In a study of Head Start children, inhibition and cognitive flexibility predicted kindergarten math and phonemic awareness when children were followed longitudinally from preschool into kindergarten, indicating that executive functions were important during the transition into formal schooling (Blair & Razza, 2007). Similarly, Espy and colleagues found that preschool children with higher inhibition and working memory scores performed better on a preschool math assessment than peers with lower inhibition and working memory (Espy et al., 2004). These studies suggest that executive functions play an important role in learning as early as preschool.

The prevailing explanation for these effects is that executive functions are involved in the direct manipulation of information held in consciousness (Altemeier et al., 2006; Blair & Razza, 2007). Neuroimaging techniques have allowed researchers to identify several brain regions that show increased activation during the performance of specific executive tasks (Blasi et al., 2006; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004). These regions include the prefrontal cortex, involved in maintaining representations of goals and selecting appropriate action schemes (Miller & Cohen, 2001; Pennington & Ozonoff, 1996; Ridderinkhofet al., 2004); the anterior cingulate cortex, which is activated when participants are asked to choose between competing response options and signals when errors have been committed (Luu & Tucker, 2002); and the parietal lobe, involved in allocating attention resources (Chein & Schneider, 2005).

The processes performed in these regions form a domain-general cognitive control system that is activated when people perform novel or difficult tasks (Chein & Schneider, 2005). With practice, activation in these regions decreases, suggesting that experience and learning lead to reduced dependence on the executive system (Chein & Schneider, 2005; Luu, Tucker, & Stripling, 2007). Thus, evidence indicates that, when faced with a novel learning situation, executive functions are directly involved in maintaining the goals and rules of the task, inhibiting irrelevant information, selecting an appropriate response, and monitoring for errors.

Although there is little doubt that executive functions are directly involved in information processing, there may be additional pathways that account for the effects of executive functions on achievement. The brain regions involved in executive functions are closely interconnected with regions that govern motor activity and emotion (Miller & Cohen, 2001). In addition to information processing, therefore, executive functions may be involved in regulating the types of behaviors and attitudes that make up approaches to learning.

The majority of studies linking executive functions to behavior in children have focused on behavior problems and social skills (Nigg, Quamma, Greenberg, & Kusche, 1999; Riggs, Blair, & Greenberg, 2003; Schonfeld, Paley, Frankel, & O'Connor, 2006). These studies show that executive functions are negatively related to internalizing and externalizing behaviors and positively related to social skills. Beyond this, however, evidence indicates that executive functions are involved in regulating behaviors that are directly relevant to learning. In a study of school-age children, teacher ratings of impulsivity, hyperactivity, and inattention were correlated with performance on the Wisconsin Card Sorting Task, a common measure of inhibition and cognitive flexibility (Riccio, Hall, Morgan, Hynd, & Gonzalez, 1994). In middle childhood, children who had been identified by their mothers as "hard to manage" at age four had lower inhibition than typical peers and were rated by testers as having higher instances of meaningless repetitive behaviors and inattentiveness during testing (Brophy, Taylor, & Hughes, 2002). In other studies, executive functions have been positively related to teacher ratings of on-task behavior (Blair et al., 2005; Blair & Peters, 2003). Taken together, this research indicates that executive functions are involved in maintaining attention, suppressing extraneous movement, and staying on-task in learning situations, all of which are considered important components of approaches to learning.

Executive functions may be especially important for young children at risk. Evidence indicates that cognitive inhibition is more strongly related to achievement in low-income children than middle- income children, and that high executive functions are related to resilience in at-risk children and adolescents (Buckner, Mezzacappa, & Beardslee, 2003; Meade, 1981). Children exposed to sociodemographic risk factors, including low family income and low parent education, tend to score lower on executive function tasks than children not at risk (Ardila, Rosselli, Matute, & Guajardo, 2005; Meade, 1981; Noble, Norman, & Farah, 2005). Since executive functions contribute significantly to achievement, it is essential to better understand how they impact school readiness among at-risk children. Exploring relationships between executive functions, approaches to learning, and school readiness is an important step in this process.

Approaches to learning. A growing body of literature indicates that positive approaches to learning are critical to school readiness in preschool children (Kagan et al., 1995; McWayne et al., 2004; Schaefer & McDermott, 1999). In fact, children with poor approaches to learning may be at risk for difficulty transitioning into formal schooling. Kindergarten teachers consider these children to be at high risk for maladjustment to first grade and are more likely to refer them for special education services than their peers (Cooper & Farran, 1988; Cooper & Speece, 1988). Children exposed to multiple risk factors may be at particular risk for developing poor approaches to learning. In one study, children with low approaches to learning scores were more likely than peers to come from single-adult households and homes with poor literacy environments, as well as having parents with low educational attainment and low occupational status (McClelland, Morrison, & Holmes, 2000).

On the other hand, positive approaches to learning may serve a protective role during the transition to elementary school. In studies of preschool, kindergarten, and first grade children, higher approaches to learning scores predicted higher achievement test scores and teacher-assigned grades both concurrently and longitudinally (Alexander, Entwisle, & Dauber, 1993; McClelland et al., 2000; McWayne et al., 2004). Perhaps most importantly, approaches to learning consistently predict achievement beyond the effects of cognitive ability (Alexander et al., 1993; McClelland et al, 2000; Yen, Konold, & McDermott, 2004). In effect, poor approaches to learning function as a risk factor and positive approaches to learning function as a protective factor. Fostering positive approaches to learning, therefore, is vital to preparing Head Start children for school.

The Current Study

To effectively promote school readiness among at-risk children, it is important to understand the role of domain-general skills like executive functions and approaches to learning. Previous research has established that (1) executive functions positively predict academic achievement; (2) executive functions are related to observable behaviors; and (3) positive approaches to learning are related to achievement. Since executive functions are theorized to be involved in the regulation of behavior, they may directly impact approaches to learning. However, researchers have not yet examined whether executive functions predict approaches to learning, or whether the effects of executive functions on school readiness are mediated by approaches to learning.

The current study addressed these important questions by testing four hypotheses: first, that executive functions would positively predict school readiness; second, that executive functions would positively predict approaches to learning; third, that approaches to learning would positively predict school readiness; and fourth, that approaches to learning would significantly mediate the relationship between executive functions and school readiness. The study used a multi-method, multi-informant approach which included direct assessments, teacher ratings, and observations, and extended previous literature by examining the focal constructs in at-risk preschool children. Four-year-old Head Start children were assessed on measures of executive functions, approaches to learning, and school readiness, with an age-normed measure of receptive vocabulary included as a control for general verbal ability. Structural equation models were then used to test the study's four hypotheses.

Chapter 2: Method

Participants

As part of a larger study that focused on validating an assessment of preschool science, data were collected on a sample of 260 preschool children enrolled in Head Start centers in a large, urban, South Florida county. Children were drawn from 28 classrooms in six centers. Children in participating classrooms were stratified by age and gender and eight children from each classroom were randomly selected (four boys and four girls when possible). Of these, 179 children over the age of four were further assessed on the executive functions measures; three centers with only a single participating classroom were not included in the current study due to time and testing constraints. The mean age of this subsample at the start of the school year was 51.4 months (*SD* = 4.9 months) and 50% were female. For two children, ethnicity data were not available. Of the remaining children, 74% were black/African American, 22% were Hispanic/Latino, 0.6% were white, and 3.4% were biracial or another ethnicity.

Procedure

Approval for this study was obtained from the university's IRB. For all direct assessments, children were tested in an environment as free from distraction as possible and were given stickers after each assessment. All assessments were administered by trained graduate and undergraduate research assistants. For the executive functions assessment, tasks were administered by one research assistant while a second research assistant recorded the child's responses.

For the classroom observation, observers were trained by an experienced coder until they reached 80% agreement within one point on master-coded videos. Observers who failed to reach agreement during initial training conducted additional field observations with reliable coders until reliability was reached. Observations were conducted in cycles, with ten minute observation periods followed by five minutes to complete ratings. Children were observed for four cycles each for a total of 40 minutes across one morning. Observers typically observed three children per morning, so observation cycles were approximately 45 minutes apart.

The order of the assessments was planned to maximize the effectiveness of these data for use in a mediation model. School readiness assessments were conducted in the fall and spring. Verbal ability was assessed in January. The executive functions battery was administered in early February. Child observations of approaches to learning were conducted in late February and March, and teacher ratings were collected in March. Demographic data on participating children (date of birth, ethnicity, and sex) were obtained from center records at the start of the school year. Teachers were compensated with a $20 gift card upon completion of the rating scales.

Measures

Executive functions. Executive functions were directly assessed using a battery of six tasks developed by Blair and Willoughby (2006) for use with preschool children from a wide range of economic backgrounds. The tasks were designed to tap into inhibition, cognitive flexibility, and working memory. The six tasks were administered in a fixed order as follows:

Spatial Conflict (inhibition): Children were given a card with a picture of two round "buttons," one on the left and one on the right. The child was then shown a series of pictures with arrows pointing left or right. The child was asked to touch the button corresponding to the direction of the arrow. Easier items presented the arrow in the center of the page, while more difficult items showed the arrow on the left or right side with the arrow pointing in a direction incongruous with its placement (e.g., an arrow on the right side pointing left). Children were given 2 practice trials and 37 test items. Scores represent the percent correct on the 12 items which required children to switch response side from one item to the next. This scoring method was chosen to capture children's performance on the items requiring the highest level of inhibition. Cronbach's alpha for this item set was .89, indicating high internal consistency.

Test-retest reliability was determined by the authors of the measure using a sample of 141 four-year-old children tested twice on the task battery within two weeks (M. Willoughby, personal communication, 5/7/2009). The correlation between the two administrations of the spatial conflict task was .72.

Operation Span (working memory): Children were shown pictures of houses that contained a colored circle and a picture of an animal and were asked to identify the color of the circle and the animal in each house. The page was turned to show the children empty houses and children were asked to recall which animal had been in each house. The early pages showed only one house per page and the task increased in difficulty until the pages showed four houses. There were a total of 19 items. Scores represent percent correct and had a Cronbach's alpha of .74. Test-retest reliability for this task was .68 (M. Willoughby, personal communication, 5/7/2009).

Something's the Same (cognitive flexibility): Children were shown pictures that varied along three dimensions: size, shape, and color. On the first page, children were shown two pictures that were the same on at least one dimension. On the following page, children were shown a third picture that was the same as one of the first pictures on one dimension. The child had to choose which of the first two pictures was the same as the new picture. For example, on one item children were shown two large cats, one red and one blue. Children were oriented to the similarity between the pictures ("Here are two pictures. Something's the same. They're both cats."). Next, children were shown a page with the two cats plus a small red flower and were asked "Which of these pictures is the same as *this* one?" The correct response was to choose the red cat on the basis of color. To answer correctly, children needed to orient to the similarity of the first two pictures and then flexibly re-orient to identify the similarity shared with the new picture. There were 20 scored items. Scores represent percent correct and had a Cronbach's alpha of .81. Test-retest reliability for this task was .64 (M. Willoughby, personal communication, 5/7/2009).

Silly Sounds Game (inhibition): Children were shown pages that had drawings of cats and dogs. Each page had a cat and a dog, but the animals' positions switched so that the dog sometimes appeared on the left and sometimes on the right. Children were first asked what sound a dog makes and what sound a cat makes. Children were then told, "When I point to the cat, make the sound that a dog makes; when I point to the dog, make the sound that a cat makes." During testing, the tester prompted the child to make a sound by pointing to the animal on the child's left, then the animal on the child's right, and then turned to a new page. To respond correctly, children needed to inhibit the prepotent response (to bark when the tester points to a dog and meow when the tester points to a cat) and give a non-dominant response (meow for the dog and bark for the cat). Children were given 3 practice trials and 36 scored items. Scores represent percent correct. Cronbach's alpha for the task was .91. Test-retest reliability was .69 (M. Willoughby, personal communication, 5/7/2009).

Pick the Picture Game (working memory): Children were shown multiple pages that contained the same pictures arranged in different orders. Children were first asked to touch a picture. Then, on subsequent pages, children were asked to "touch a new picture that is not the same as the one(s) you touched before, so that each picture gets a turn." The first item sets had two pictures and the number of pictures per set increased up to six pictures. Responses were correct if the child pointed to a picture s/he had not yet pointed to in that set. There were 2 practice items and 30 test items. Scores represent percent correct excluding the first item in each picture set (which was automatically correct). Cronbach's alpha for the 22 scored items was .83. Test-retest reliability for this task was .68 (M. Willoughby, personal communication, 5/7/2009).

The Pig Game (inhibition): A red button was placed before the child. Children were then shown a series of pictures of animals and asked to "press the red button every time you see an animal, but not when it is a pig." Successful responding required children to learn a response (pushing the button) and inhibit this response when cued by the picture of the pig. There were 8 practice items and 24 test items. Scores represent percent correct on the seven items that showed a pig. Cronbach's alpha for those items was .89. Test-retest reliability for this task was .60 (M. Willoughby, personal communication, 5/7/2009).

Approaches to learning. Approaches to learning were assessed using a rating scale and a classroom-based observation. Teachers completed the Preschool Learning Behaviors Scale (PLBS) for each child in the study (McDermott, Green, Francis, & Stott, 2000). The PLBS is a 29-item teacher rating scale designed to assess approaches to learning in preschool children. Teachers rate behaviors in three areas: competence motivation (e.g., “shows a lively interest in the activities”), attention/persistence (e.g., “pays attention to what you say”), and attitude toward learning (e.g., “gets aggressive or hostile when frustrated”). Each behavior is rated on a three-point scale (*most often applies* = 0, *sometimes applies* = 1 and *doesn’t apply* = 2). Raw scores were converted into area conversion t-scores ($M = 50$, $SD = 10$) based on the national standardization sample. Alphas for the three subscales on the standardization sample were .85, .83, and .75, respectively (McDermott et al., 2000), and in the current sample were .86, .87, and .77.

The observation consisted of the Task Orientation subscale of the inCLASS, an observational rating scale of preschool classroom behavior (Downer, Booren, Lima, Luckner, & Pianta, *under review*). For this subscale, children were rated on three items (engagement, self-reliance, and behavior control) over the course of a typical morning in their classrooms. Items were rated on a seven point scale. Children were rated high on engagement if they maintained focus on an appropriate activity and demonstrated interest and enthusiasm. Children were rated high on self-reliance if they showed initiative by independently seeking out activities or were able to persist calmly in the face of difficult tasks. Children were rated high on behavior control if they showed physical awareness and matched their level of arousal to that of their classmates. Twenty percent of cycles were double coded for purposes of reliability. Mean inter-rater agreement (percent agreement within one point on the rating scale) was 90% for engagement, 77% for self reliance, and 88% for behavior control.

The inCLASS was developed based on an extensive review of early childhood literature (Downer et al., 2008). In a validation study of 164 three- to five-year old children, the Task Orientation subscale correlated positively with teacher ratings of social skills, task orientation, and emotion regulation (Downer et al., 2008). Furthermore, Task Orientation scores significantly predicted teacher ratings of language and literacy and were sensitive to age differences between three-, four-, and five-year-olds (Downer et al., 2008).

School readiness. Children's school readiness was assessed in the fall and spring using the Learning Express (McDermott, Angelo, Waterman, & Gross, 2005), a criterion-referenced direct assessment developed for use with Head Start children that produces subscale scores for vocabulary, math, listening comprehension, and alphabet knowledge. The Learning Express has two parallel forms to allow for valid retesting. Items are ordered by difficulty within each subscale and children are tested only on items within their ability range. Scores are calculated using item-response theory (M = 200, SD = 50). Data collected during the preceding year demonstrate that the Learning Express significantly correlates with the PLBS as well as teacher-rated language and literacy and early math (Vitiello, Dominguez E., Maier, Fuccillo, & Greenfield, *in preparation*).

Verbal ability. The Peabody Picture Vocabulary Test-III (PPVT-III; Dunn, Dunn, Williams, & Wang, 1997) is a brief measure of receptive vocabulary that has been widely used as a proxy for verbal ability (e.g., Blair, 2003; Carlson & Wang, 2007). The PPVT-

III has two parallel forms that can be administered interchangeably. In the current study, children were randomly assigned to receive one of the two forms. Each item of the PPVT-III consists of four black-and-white pictures. The examiner reads a word and asks the child to point to the picture that most closely corresponds to the word. Items are organized into sets that are ordered by difficulty; children were only tested on sets within their ability range to reduce testing demands. The PPVT-III forms A and B correlate highly with the Wechsler Intelligence Scale for Children (.91 and .92, respectively; Dunn et al., 1997).

Analytic Approach

Analyses were conducted in several steps. First, descriptive statistics for each variable were generated and variables showing non-normality were transformed. Second, preliminary analyses were run to test for correlations between study variables and to identify effects of sex and ethnicity. Third, the main study hypotheses were tested using structural equation modeling.

Structural equation modeling (SEM) is an analytic technique that uses covariances to estimate relationships between variables (Kline, 2005). Unlike traditional regression, SEM allows the researcher to increase the reliability of scores by creating latent variables that are free of measurement error. Latent variables are created by using multiple observed scores to identify underlying (latent) characteristics. Latent variables can then be entered into models which test relationships between the constructs of interest. In the current study, latent variables were created for executive functions and approaches to learning.

In SEM, model fit indices are used to determine whether the model being tested closely reproduces the pattern of relationships seen in the observed data (Kline, 2005). Commonly used fit indices include the chi-squared test, the comparative fit index (CFI), the root mean square error of the approximation (RMSEA), and the standardized root mean square residual (SRMR). Because these indices represent the deviation of the model-implied variance-covariance structure from the observed variance-covariance structure (ie., "badness" of fit), smaller values generally represent closer fit of the model to the data. In the current study, the following values were considered to represent adequate fit: a non-significant chi-squared test, CFI $\geq .98$, RMSEA $\leq .06$, and SRMR $\leq .08$ (Kline, 2005).

An additional advantage of SEM is that it allows for the inclusion of participants that are missing data on one or more measures. In the current study, 1% of possible data points were missing, which would have resulted in the exclusion of 17% of the participants had listwise deletion been used. To prevent exclusion of these cases, missing data were handled using full information maximum likelihood, a method which makes use of all available data in estimating each covariance (McCartney, Burchinal, & Bub, 2006). Maximum likelihood produces estimates that are less biased than other approaches to missing data, such as listwise deletion, single imputation, and mean imputation (McCartney et al., 2006).

Chapter 3: Results

Descriptive Analyses and Data Preparation

Descriptive statistics for all assessments are shown in Table 1. Variables showing high skew or kurtosis, defined here as the ratio of the statistic to the standard error greater than ±3 (Kline, 2005), were transformed. Three types of transformations were tested (natural log, square root, and inverse), and the most effective transformation in each case was retained. After transforming non-normal variables, all study variables except age and sex were converted into *z*-scores. This removed the variables' metrics and reduced the interpretability of the results, but was necessary for estimation of the structural models because the variables had widely differing variances, which can lead to model nonconvergence (Kline, 2005). Because *z*-scores were used instead of the variables' original metrics, results of the structural equation models are reported as standardized betas.

Preliminary Analyses

Sex and ethnicity. Independent samples *t*-tests were used to test for differences between boys and girls on all study variables. Results showed several significant sex differences. For the executive functions measures, girls scored higher than boys on two inhibition tasks (the Silly Sounds Game ($t(170) = -2.021$, $p = .045$) and the Pig Game ($t(174) = -3.251$, $p = .001$)) and one working memory task (Pick the Picture ($t(174) = -2.232$, $p = .027$)). On the approaches to learning variables, girls were rated higher than boys on attention/persistence ($t(173) = -2.572$, $p = .011$), behavior control ($t(164) = -2.676$, $p = .008$), and engagement ($t(164) = -3.331$, $p = .001$), and marginally higher on attitude toward learning ($t(174) = -1.929$, $p = .055$). For school readiness, girls scored higher than boys on math in the fall ($t(176) = -2.201$, $p = .029$) and listening comprehension in the spring ($t(173) = -3.185$, $p = .002$). There was no significant sex difference on verbal ability.

For ethnicity, *t*-tests were used to compare African American children to all other children because sample sizes were not large enough to treat each ethnicity as a separate group. For the executive functions variables, African American children scored lower than other children on the three inhibition tasks (Spatial Conflict ($t(175) = 1.991$, $p = .048$), the Silly Sounds game ($t(168) = 2.046$, $p = .042$), and the Pig Game ($t(173) = 2.642$, $p = .009$)) and the cognitive flexibility task (Something's the Same ($t(175) = 2.712$, $p = .007$)). For approaches to learning, African American children were rated higher than other children on competence motivation ($t(173) = -2.610$, $p = .010$). For school readiness, African American children scored marginally lower than other children on fall listening comprehension ($t(174) = 1.902$, $p = .059$) but higher than others on spring alphabet knowledge ($t(172) = -2.070$, $p = .040$). There was no difference between groups on verbal ability.

Correlations. Correlations between all study variables are reported in Table 2. Overall, the relationships were in the expected directions. Age was positively correlated with components of executive functions and school readiness, although it was related to only one of the six approaches to learning variables (engagement, $r = .29$, $p < .01$). There were several positive correlations between the executive functions variables and approaches to learning, ranging from .02 to .25. More consistent positive correlations were found between executive functions and school readiness, ranging from .02 to .40.

Constructing Latent Variables

Before testing relationships between constructs, data were reduced by loading individual indicators onto latent variables representing larger constructs. Latent variables were tested for executive functions, approaches to learning, and school readiness. For executive functions and approaches to learning, the true underlying factor structure was unknown, although certain combinations were likely based on how the measures were conceptualized. To produce the most valid, stable latent factors for each construct, the following procedures were used. First, the sample of 179 children was randomly split into two subsets. The first subset of children (*n* = 91) was subjected to exploratory factor analysis with varimax rotation using MPlus (Muthen & Muthen, 1998). Because both executive functions and approaches to learning had six indicators, the upper limit on the number of possible factors was set to three for each analysis. The best factor solutions were determined based on eigenvalues greater than one, root mean square residuals (RMSEA) less than .06, and theory. Second, the resulting factor solutions were tested on the second subset of children (*n* = 88) using confirmatory factor analysis, and adjustments to the factor structures were made as necessary. Third, the factor structures were imposed on the full sample of children. Additional adjustments to the models were made, and the final resulting factor structures were used to test the study's main hypotheses.

Executive functions. The exploratory factor analysis of the six executive functions variables resulted in three potentially viable factor solutions, all with RMSEAs below the cut-off of .06. Eigenvalues indicated that the two-factor solution was most appropriate, so that one was adopted (see Table 3). The RMSEA for this solution was .018. Four of the indicators loaded onto one factor (Spatial Conflict (inhibition), the Pig Game (inhibition), Something's the Same (cognitive flexibility), and Pick the Picture (working memory)), and Operation Span (working memory) loaded onto a second factor. The Silly Sounds Game (inhibition) did not load at the .40 level onto either factor, and was therefore dropped from subsequent analyses.

The initial confirmatory factor analysis confirmed the exploratory results without modifications, resulting in good model fit ($\chi^2(5) = 1.902$, $p = .863$, CFI = 1.000, RMSEA = .000, SRMR = .027). This model was then fit to the full sample and again resulted in good fit without modifications ($\chi^2(5) = 5.521$, $p = .356$, CFI = .993, RMSEA = .024, SRMR = .032). The final latent variable model for executive functions is presented in Figure 1. The resulting factors represented a general executive functions factor (EF) which included measures of inhibition, flexibility, and one of the working memory tasks, and a second indicator of working memory (WM). The loading of Spatial Conflict on the EF factor was slightly lower than desirable but was statistically significant (.397, t = 3.403, $p < .001$). EF was positively correlated with WM ($r = .297$, $p < .01$).

Approaches to learning. Exploratory factor analysis of the approaches to learning indicators suggested that solutions with two or three factors fit the data. Eigenvalues indicated that the two-factor solution was the best so this one was retained (see Table 4). The RMSEA was .052. Self-reliance did not load onto either factor, and was therefore dropped from subsequent models. Additionally, although behavior control loaded on the second factor slightly below the .40 level, it was retained in the confirmatory factor analysis in the interest of retaining as much of the observational data as possible.

Confirmatory factor analysis on the second subset of children confirmed the two-factor structure with one modification: the residual variance of attention/persistence was fixed to zero. Fit indices indicated adequate fit to the data ($\chi^2(5) = 9.123$, $p = .104$, CFI = .981, RMSEA = .097, SRMR = .047). This model was then tested on the full sample. Based on model modification indices, the residual variance of attention/persistence was freed, but the residual variances of behavior control and competence motivation were allowed to correlate (see Figure 2). This resulted in good fit to the data ($\chi^2(3) = 5.473$, $p = .140$, CFI = .994, RMSEA = .068, SRMR = .023). With these modifications, the two factors represented teacher-reported approaches to learning (ATL-teacher) and observed approaches to learning (ATL-observed). The two factors were correlated at .518 ($p < .001$).

School readiness. The school readiness indicators (fall and spring measures of vocabulary, math, listening comprehension, and alphabet knowledge) were initially loaded onto two latent factors representing fall and spring school readiness. This model showed acceptable fit to the data when indicators were allowed to correlate across time points (e.g., fall math with spring math; $\chi^2(15) = 39.922$, $p = .003$, CFI = .974, RMSEA = .086, SRMR = .037). However, in subsequent analyses it was difficult to obtain good model fit using these factors and modification indices suggested that these latent factors did not adequately allow for relationships between executive functions, approaches to learning, and individual components of school readiness. Therefore, in subsequent analyses, school readiness variables were entered as indicators rather than latent variables.

Structural Models

After establishing the latent variable models, relationships between the constructs were tested to address the study's main hypotheses. Based on preliminary findings, all pathways were tested controlling for age, sex, ethnicity, and verbal ability. Covariates were dropped from the model if they were found to be non-significant. The appropriateness of nested models was tested using the chi-squared difference test ($\Delta\chi^2$).

Hypothesis 1: Executive functions significantly predict school readiness. EF and WM were tested as predictors of spring school readiness controlling for fall school readiness and the covariates. Several pathways were non-significant and were therefore trimmed from the model (see Table 5 for complete results and Figure 3 for a simplified path model). The trimmed model showed good fit to the data ($\chi^2(86) = 99.368$, $p = .154$, CFI = .988, RMSEA = .029, SRMR = .051) and did not exhibit significantly worse fit than the full model ($\Delta\chi^2(30) = 36.029$, $p = .207$). This model suggested that EF was significantly and positively related to spring vocabulary, math, and listening comprehension controlling for fall school readiness. EF was not related to spring alphabet knowledge. Furthermore, WM did not significantly predict school readiness in any of the domains, and was not significantly correlated with EF once the covariates were controlled.

Hypothesis 2: Executive functions significantly predict approaches to learning. EF and WM were tested as predictors of the ATL-teacher and ATL-observed latent factors, controlling for the covariates. The initial model showed poor fit to the data ($\chi^2(53) = 98.612$, $p < .001$). Non-significant pathways were trimmed and several error variances were allowed to correlate (see Table 6 for full results and Figure 4 for the simplified path model), resulting in adequate fit to the data ($\chi^2(58) = 84.742$, $p = .013$, CFI = .957, RMSEA = .051, SRMR = .047). Results indicated that EF was significantly and positively related to teacher-reported and observed approaches to learning. WM was marginally related to teacher-reported approaches to learning but not related to the observation.

Hypothesis 3: Approaches to learning significantly predict school readiness. ATL-teacher and ATL-observed were tested as predictors of spring school readiness, controlling for fall school readiness and the covariates. The initial model showed poor fit to the data ($\chi^2(52) = 104.529$, $p < .001$). As above, non-significant pathways were trimmed and several error variances were allowed to correlate (see Table 7 for full results and Figure 5 for the simplified path model), resulting in adequate fit ($\chi^2(82) = 104.773$, $p = .046$, CFI = .985, RMSEA = .039, SRMR = .064). The modified model suggested that teacher-reported approaches to learning significantly predicted spring math, listening comprehension, and alphabet knowledge but did not predict spring vocabulary. Furthermore, observed approaches to learning were significantly correlated with fall listening comprehension but did not predict any of the spring school readiness indicators.

Hypothesis 4: Approaches to learning significantly mediate the relationship between executive functions and school readiness. To test the final model, relationships between executive functions, approaches to learning, and school readiness were tested simultaneously, using results from the previous models to specify pathways. The WM variable was left out of this model because it had shown only marginal relationships to other constructs in previous analyses. The initial model showed adequate fit to the data ($\chi^2(134) = 169.633$, $p = .002$, CFI = .970, RMSEA = .047, SRMR = .041). Once non-significant pathways were removed, the model exhibited acceptable fit to the data ($\chi^2(146) = 191.817$, $p = .007$, CFI = .972, RMSEA = .042, SRMR = .047). Although the chi-squared test remained significant, the other fit indices were within appropriate limits.

The chi-squared difference test indicated that the trimmed model did not exhibit worse fit than the previous model ($\Delta\chi^2(25) = 22.184$, $p = .375$), so the more parsimonious model was retained. Table 8 provides full results and Figure 6 shows a simplified path model.

The indirect pathways from executive functions to school readiness via approaches to learning were tested to determine whether the proposed mediation was significant. ATL-observed was not tested as a mediator because it was not related to school readiness outcomes. Also, the indirect pathway to vocabulary was not tested because the relationship between ATL-teacher and vocabulary was non-significant. The remaining indirect pathways were significant: for spring math, $\beta = .061$, $z = 2.427$, $p < .05$; for spring listening comprehension, $\beta = .056$, $z = 2.018$, $p < .05$; and for spring alphabet, $\beta = .051$, $z = 1.976$, $p < .05$. These results indicated that teacher-reported approaches to learning significantly mediated the relationship between executive functions and spring school readiness scores, controlling for fall school readiness, verbal ability, age, sex, and ethnicity.

Chapter 4: Discussion

The primary purpose of this study was to test the hypothesis that approaches to learning would mediate the relationship between executive functions and school readiness in Head Start preschoolers. This hypothesis, along with the three related hypotheses, was supported. Executive functions significantly and positively predicted both approaches to learning and school readiness. Approaches to learning also significantly predicted school readiness. When relationships between all three constructs were tested simultaneously, approaches to learning significantly mediated the pathways from executive functions to math, listening comprehension, and alphabet knowledge.

Latent Variables

The first step of the analyses was to identify the dimensionality of the constructs under study using exploratory and confirmatory factor analysis. The measurement models revealed several interesting findings.

Executive functions. Analysis of the executive functions data revealed that the tasks assessed two aspects of executive functions rather than three. The factors that emerged were best described as an inhibition/flexibility factor reflecting general executive skills and a weaker working memory factor that included a single task. Similar factor structures have been found by other researchers studying executive functions in children (Beveridge, Jarrold, & Pettit, 2002; Brocki & Bohlin, 2004; St. Claire-Thompson & Gathercole, 2006).

Results from this measurement model reflect an ongoing debate about the true nature of executive functions. Components of executive functions tend to show low to moderate correlations with one another, leading some researchers to conclude that they are relatively distinct processes (Salthouse & Davis, 2006). Others have hypothesized that executive functions reflect a single underlying mechanism, most commonly associated with inhibitory control (Carlson & Wang, 2007; Wiebe, Espy, & Charak, 2008). The current findings suggest that there is a degree of overlap between inhibition and flexibility but separation between this factor and working memory capacity, with a small to moderate correlation between the two components. These findings are in keeping with the emerging perspective that executive functions include several distinct but related components (Garon, Bryson, & Smith, 2008). The number of components, operational definitions of each, and the degree of relatedness between them are still debated (Wiebe et al., 2008), but behavioral studies and studies involving brain imaging support this view (Ridderinkhofet al., 2004).

Additionally, it must be noted that it has proven difficult to design tasks that tap into individual components of executive functions, especially in young children (Hughes & Graham, 2002). This is highlighted by the fact that several of the tasks did not load on factors as anticipated: Pick the Picture, which was designed to tap into working memory, loaded onto the inhibition/flexibility factor. This may reflect the specific demands of this task, which required children to pick a new picture on each page. If children found certain pictures appealing, it may have been difficult to inhibit pointing to those pictures in order to select new pictures. Furthermore, the Silly Sounds Game (inhibition) did not load significantly with either factor, despite the fact that it was correlated with several other tasks. Ongoing research in this area will need to work toward separating measurement challenges from the true underlying structure of these cognitive processes.

Approaches to learning. The subscales of the teacher report and two dimensions of the observational measure loaded onto separate factors. This is likely due in part to shared method variance between items from the same measure. However, it is also the case that the two measures emphasized slightly different sets of behaviors. The teacher report had a greater emphasis on children's motivation and attitudes, while the observation focused more on physical activity level and arousal (Downer et al., 2008; McDermott et al, 2000). Using both of these measures likely produced a fuller picture of children's approaches to learning than either would have alone.

One dimension of the observational measure, self reliance, did not load onto either factor. This may be because the behaviors rated on this dimension (initiative, self-direction, and persistence in the face of challenge) occur infrequently in preschool children, although the variable was normally distributed and showed adequate variability. A more likely explanation is that this item was more difficult to code than the others and therefore contained more measurement error. Observers reported having difficulty rating this item and it had the lowest inter-rater agreement of the three observational dimensions.

School readiness. Although the school readiness indicators loaded into factors that fit the data, these factors were difficult to fit into the larger models. This may be due, in part, to the fact that the models were fairly complex given the number of participants. However, it may be inappropriate to group disparate aspects of achievement into a single factor. Research indicates that literacy and math draw upon different cognitive processes and therefore may not represent indicators of the same latent skill set (Posner, DiGirolamo, & Fernandez-Duque, 1997; Prabhakaran, Rypma, & Gabrieli, 2001).

Results from the current study, showing that executive functions and approaches to learning differentially predicted the achievement indicators, support this interpretation.

Effects of Executive Functions on School Readiness

Substantial prior research supported the hypothesis that executive functions would positively predict school readiness (e.g., Bull & Scerif, 2001; Lee et al., 2004). Because the current study controlled for fall school readiness scores, results further suggested, at a very preliminary level, that executive functions predicted change in school readiness. In other words, children with higher executive functions scores made greater gains in vocabulary, math, and listening comprehension from fall to spring than children with lower scores. Since executive functions are theorized to be involved directly in learning, as well as regulating learning-related behaviors, it may be reasonable to infer that children with stronger executive skills are more efficient learners. It is an important finding, though, because it implies that executive functions may be related to achievement gains in preschool children. Research with slightly older children has shown that inhibition and flexibility are related to achievement level but not achievement growth (Vitiello, Dominguez, Maier, Fuccillo, & Greenfield, *under review*), perhaps owing in part to the high rank-order stability of achievement trajectories among school-aged children (Entwisle, Alexander, & Olson, 1997; Vitiello et al., *under review*). If the current findings are supported by subsequent longitudinal studies, it may be that the preschool years represent a period during which improving children's executive functions could boost initial achievement levels and place children on higher achievement trajectories. Taken together, these findings highlight the importance of understanding executive functions in preschool-aged children and the potential importance of targeting these skills as early as possible.

Not all of the relationships between executive functions and school readiness were significant: surprisingly, working memory did not predict outcomes. This contrasts previous studies in which working memory did predict achievement, particularly math (Bull & Scerif, 2001; Espy et al., 2004). There are at least two possible explanations for the current lack of findings. First, the working memory variable here was a single indicator. It is possible that this indicator included a greater degree of error than a latent factor would have, decreasing the power to find significant effects.

Second, the Operation Span task appears to be a fairly pure test of working memory, with little reliance on other executive skills. In contrast, many previous studies have used working memory tasks that tap inhibition and flexibility to a greater extent. The Operation Span task taxed children's working memory capacity by asking them to remember animals, colors, and order of presentation. Other working memory tasks, such as backwards digit recall (Gathercole, Brown, & Pickering, 2003; Geary, Hamson, & Hoard, 2000) or delayed alternation (Espy et al., 2004), arguably rely heavily on inhibition and flexibility in addition to working memory. This reflects, in part, a lack of clarity in the use of the term "working memory," which has been used to refer either to the full set of executive functions (e.g., Baddeley's model of working memory and the central executive, Baddeley, 1996) or to working memory *capacity*, as the term is used here. It may be the case that tasks tapping working memory capacity are less reliable predictors of achievement, or that they are good predictors of achievement later in childhood but not as early as preschool.

The inhibition/flexibility factor was related to vocabulary, math, and listening comprehension, but not alphabet knowledge. Judging by the magnitude of the standardized coefficients, executive functions were more strongly related to math and listening comprehension than vocabulary. The fact that executive functions are more predictive of math than literacy is fairly well established in the literature (Blair & Razza, 2007). Researchers have hypothesized that performing math tasks requires active cognitive regulation and information processing (Deschuyteneer & Vandierendonck, 2005). In adults, fMRI studies have shown activation in the prefrontal cortex while participants performed mathematical reasoning problems (Prabhakaran et al., 2001). While the math skills tested by the Learning Express seem relatively simple (counting, labeling numbers, recognizing more vs. less, etc.), the current findings suggest that even such basic skills depend heavily on executive functions.

Listening comprehension may rely on executive functions for similar reasons. Comprehension of spoken language involves listening to a stream of language and selectively responding to relevant phrases. For example, if a teacher says “We’re going on a field trip to the zoo, so I’d like you to put on your jackets and line up at the door,” children need to understand and act on certain parts of the teacher’s speech (“zoo,” “jackets,” “line up,” door”), while inhibiting focus on the less relevant parts. Research has shown that executive functions, including cognitive flexibility and retrieval from long-term storage, are significantly related to performance on comprehension tasks (Adams, Bourke, & Willis, 1999; De Beni, Palladino, Pazzaglia, & Cornoldi, 1998; Montgomery, Magimairaj, & O’Malley, 2008). Over time, the ability to selectively focus on certain phrases embedded within speech may help children assign meaning to those phrases and develop stronger comprehension skills.

The alphabet knowledge subtest, on the other hand, predominantly assesses the degree to which children can link symbols to sounds; the majority of items in the subscale test letter recognition and recall. It may be that these skills involve basic memorization or retrieval and are not as heavily dependent on inhibition and flexibility. In fact, it seems logical that alphabet knowledge would have been more highly related to working memory than other executive skills (although working memory was not related to alphabet knowledge in this study). The subtest did include items asking children to identify the first letter of a word, match a word to a picture, and read simple words, but those items were more difficult and there were fewer of them. Since previous studies have found relationships between executive functions and literacy (e.g., St. Claire-Thompson & Gathercole, 2006), it may be the case that slightly older children who are mastering more advanced reading skills rely more heavily on inhibition and flexibility.

Effects of Executive Functions on Approaches to Learning

The significant relationship between the general executive functions factor and both approaches to learning factors suggests that inhibition and flexibility support the development of attention/persistence, engagement, motivation, behavior control, and positive attitudes toward learning. The magnitudes of the relationships were relatively large: one standard deviation increase in executive functions was associated with a one-third standard deviation increase in teacher-reported approaches to learning, and half of a standard deviation increase in observed approaches to learning. This indicates that executive functions play an important role in the development of learning-related behaviors and attitudes. Although this study was correlational, it also raises the interesting possibility that intervening directly to improve children's executive functions could lead to improvements in classroom behaviors as well as achievement. Two intervention programs that focused on improving executive functions, the PATHS curriculum for elementary-aged children (Greenberg, Kusché, Cook, & Quamma, 1995) and the Tools of the Mind curriculum for preschoolers (Diamond, Barnett, Thomas, & Munro, 2007), have thus far proven effective at decreasing problem behaviors (Barnett, Jung, Yarosz, Thomas, Hornbeck, Stechuk, & Burns, 2008; Riggs, Greenberg, Kushe, & Pentz, 2006). Future interventions should additionally focus on whether directly improving children's executive functions leads to improved approaches to learning.

Effects of Approaches to Learning on School Readiness

This study confirmed previous studies by showing that approaches to learning positively predicted math, listening comprehension, and alphabet knowledge (e.g., Schaefer & McDermott, 1999). Approaches to learning predicted outcomes beyond the effects of prior school readiness scores, underscoring their importance to learning in preschool. This further demonstrates that this domain-general skill set is critical to learning across multiple domains.

As with executive functions, however, not all relationships were significant; the observational measure of approaches to learning did not predict outcomes. Several explanations for this are possible. First, the observational measure incorporated behaviors that were, to a degree, different from those rated by teachers. While the teacher measure focused on attention, persistence, motivation, and attitudes, the observational measure included task engagement and behavior control. This focus on behavior control, which included awareness of one's body in space and the regulation of arousal to match class expectations, may be less relevant to academic school readiness than the other components of approaches to learning. For example, a child who called out inappropriately during circle time or bumped into other children while getting in line would receive a lower rating on behavior control, but these behaviors themselves may not limit the child's opportunities to learn.

Additionally, classroom observations were conducted throughout the morning and were not limited to learning situations. That means that observation cycles took place during transitions, meal times, and outdoor free play as well as circle time, small group time, and indoor free play. Although only the Task Orientation subscale was used in the current study, the inCLASS provides ratings of children's teacher and peer interactions as well. Some of the classroom activities that are less learning-oriented (e.g., outdoor free play) provide excellent opportunities to observe teacher and peer interactions, but may not be ideal for rating task behaviors. If this is the case, it may be important to ensure that children are observed for additional cycles that occur during learning-oriented classroom activities.

Teacher-reported approaches to learning were not related to spring vocabulary scores, controlling for fall scores, verbal ability, and demographic variables. In reviewing past studies, it appears that most have examined approaches to learning in relation to either teacher assigned grades (Alexander et al., 1993) or composite school readiness scores (McWayne et al., 2004; Yen et al., 2004). One study that did relate receptive vocabulary to approaches to learning, using the PPVT-R, found that they did not account for significant variance in spring scores controlling for fall (McClelland et al., 2000). It may therefore be the case that vocabulary skills are not dependent on children's approaches to learning. Further research would be needed, however, to determine whether this is the case.

Mediational Role of Approaches to Learning

The main study hypothesis, that approaches to learning would mediate the relationship between executive functions and school readiness, was supported for math, listening comprehension, and alphabet knowledge. These findings suggest that executive functions' role in the development of learning-related behaviors and attitudes partially accounts for their effect on early achievement. While previous research has linked executive functions and other components of self-regulation to classroom behaviors and school readiness (Blair & Peters, 2003; Howse, Calkins, Anastopoulos, Kean, & Shelton, 2003; Howse, Lange, Farran, & Boyles, 2003), the current study directly tested a mediation model linking these three important constructs.

Interestingly, the sizes of the indirect effects were relatively small. In fact, the indirect pathways accounted for only 15.6% of executive functions' total effect on math and 12.0% of the total effect on listening comprehension. The full effect of executive functions on alphabet knowledge was accounted for by the indirect pathway, since executive functions did not directly predict alphabet knowledge; likewise, none of the relationship between executive functions and vocabulary was due to approaches to learning. The overall picture suggests that the majority of the effect of executive functions on outcomes was not mediated by approaches to learning. This raises the question of whether other mediators account for this relationship, or whether the majority of the effect is direct rather than mediated.

Studies of executive functions in typically developing children have found links to other behavioral indices, including positive relationships to social behaviors and negative relationships to internalizing and externalizing behavior problems (Riggs et al., 2003; Schonfeld et al., 2006). It is likely that these factors partially transmit the effects of executive functions to school readiness, since all three have been linked to academic outcomes (Caprara, Barbaranelli, Pastorelli, Bandura, & Zimbardo, 2000; Lonigan, Bloomfield, Anthony, Bacon, Philips, & Samwel, 1999). Given the research linking executive functions to information processing, however, it is equally likely that executive functions have a direct effect on school readiness (Gathercole & Pickering, 2000). An interesting direction for researchers to pursue would be to further tease apart the different roles that executive functions play in the development of school readiness.

Role of Covariates in the Final Model

Executive functions. The inhibition/flexibility factor was significantly predicted by verbal ability, age, and ethnicity, and marginally predicted by sex ($p < .10$). These variables jointly accounted for 60% of the variance in this factor. The dependence on verbal ability is likely due, in part, to the fact that children needed a basic level of receptive language in order to understand task instructions, a common problem in testing young children (Hughes & Graham, 2002).

The fact that age was such a strong predictor, even given the restricted range of ages in this study, highlights the fact that executive functions depend to a large extent on developmental processes. Unlike some skills that must be explicitly taught, like literacy or science, executive functions appear to be experience-expectant, meaning that typical development is likely when children are exposed to appropriate levels of stimulation

(Nelson, 2000). This does not mean that executive functions cannot be taught or trained, however. Recent studies have found that short-term, targeted interventions can be effective at increasing executive functions. Although thus far the majority of this research has focused on school-aged children with attention deficit/hyperactivity disorder (Kerns et al., 1999; Klingberg et al., 2005; Klingberg et al., 2002), studies involving preschool children suggest that executive skills training can increase inhibition and nonverbal reasoning (Dowsett & Livesy, 2000; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). For children from disadvantaged backgrounds, exposure to an enriched preschool environment such as that provided by Head Start may provide sufficient stimulation to increase the likelihood of typical development (Nelson, 2000).

Approaches to learning. Approaches to learning were significantly related to just two of the covariates, ethnicity and sex. Ethnicity was related to both teacher-reported and observed approaches to learning, while sex was related only to the observational measure. The ethnicity data is difficult to interpret because ethnicity was confounded with Head Start center in the current study. The sex difference in the observational data, however, provides further evidence that the teacher measure and the observation addressed slightly different behaviors. Results showed that girls scored slightly higher than boys on the observational measure. This may be due to differences between the two measures: the observational measure included physical control over movement. Other research has shown that, in preschool, boys show less control over motor activity than girls (Klenberg, Korkman, & Lahti-Nuuttila, 2001).

School readiness. In general, the covariates were more strongly related to fall school readiness scores than spring scores. This implies that the covariates were related to initial levels of school readiness rather than school readiness gains. There were several exceptions, however. The measure of verbal ability was significantly related to spring vocabulary scores, likely due to the fact that both assessed receptive vocabulary. Additionally, age was positively related to spring math and alphabet scores, indicating that older children made greater gains across the school year.

Limitations and Future Directions

The strengths of this study include the use of multiple direct assessments and a multi-measure, multi-informant approach to assessing children's approaches to learning. Despite these strengths, several limitations are worth noting. First, all of the key assessments were collected over the space of five months, which gave the proposed mediation process limited time to work. Conducting the study over a longer time period may have revealed stronger mediation effects than were found here. Second, the sample, which was largely African American, was drawn from an urban area in the southeastern United States and findings may not be generalizeable to other ethnic Head Start populations or non-urban contexts. Third, the fact that child ethnicity was partially confounded with center made it difficult to interpret ethnic differences on measures of executive functions and approaches to learning.

An additional limitation is that the current study did not account for dependencies between children from the same classroom. The use of multilevel modeling may have provided more precise estimates since it accounts for nestings. Due to the complexity of the models and the relatively small sample size, however, nestings were not taken into account. A previous study that used multilevel modeling found that the effects of cognitive flexibility and approaches to learning on school readiness did not vary significantly across classrooms (Vitiello, Greenfield, Munis, & George, *under review*). However, additional research is needed to confirm that the current results are robust after accounting for dependencies in the data.

In future studies, it may be interesting to further explore specific relationships between executive functions and approaches to learning. Of particular importance is the use of a broader set of working memory tasks to determine whether working memory is related to behavior and school readiness. Additionally, it may be that certain components of executive functions are related to specific aspects of approaches to learning. Use of a larger sample and a more extensive set of assessments may allow researchers to better understand these specific relationships.

It is also important to determine whether intervening with children's executive functions leads to improved behavioral and academic outcomes. If so, further work must be done to identify effective methods for teaching children this important set of cognitive skills. The current study suggests, at a very preliminary level, that increasing executive functions may impact academic school readiness to a greater degree than behavioral outcomes. Additional research is needed to confirm this finding and determine the total effect that an executive functions-based intervention could have on both sets of outcomes.

Conclusions

Findings from this study highlight the importance of executive functions to approaches to learning and academic school readiness in Head Start preschoolers. While previous studies have linked executive functions to behavior, the current study suggests that this relationship partially accounts for the effect of executive functions on early achievement. It is important to note, however, that the strongest conclusion to be drawn from this study is that executive functions support development across disparate school readiness domains, including approaches to learning and academic achievement. It is therefore especially important to better understand executive functions in at-risk preschool children, since strong executive functions may serve a protective role for these children.

Researchers and practitioners increasingly recognize that school readiness and early achievement are complex, multi-faceted constructs, and that preparing children for school requires that they be exposed to many different types of experiences (Stipek, 2006). Rather than focusing primarily on academic skills, preschool may be the time to support the development of domain-general skills like executive functions and approaches to learning, skills which predict later achievement across multiple domains. While academic instruction is critical to closing the achievement gap, helping children develop executive skills and positive dispositions toward schooling may be just as important.

Chapter 5: References

Adams, A., Bourke, L., & Willis, C. (1999). Working memory and spoken language comprehension in young children. *International Journal of Psychology, 34*(5/6), 364-373.

Alexander, K. L., Entwisle, D. R., & Dauber, L. S. (1993). First-grade classroom behavior: Its short- and long-term consequences for school performance. *Child Development, 64*(3), 801.

Altemeier, L., Jones, J., Abbot, R. D., & Berninger, V. W. (2006). Executive functions in becoming writing readers and reading writers: Note taking and report writing in third and fifth graders. *Developmental Neuropsychology, 29*(1), 161-173.

Ardila, A., Rosselli, M., Matute, E., & Guajardo, S. (2005). The influence of the parents' education level on the development of executive functions. *Developmental Neuropsychology, 28*(1), 539-560.

Baddeley, A. (1996). Exploring the central executive. *Quarterly Journal of Experimental Psychology, 49*(1), 5-28.

Barnett, W. S., Jung, K., Yarosz, D. J., Thomas, J., Hornbeck, A., Stechuk, R., & Burns, S. (2008). Educational effects of the Tools of the Mind curriculum: A randomized trial. *Early Childhood Research Quarterly, 23*(3), 299-313.

Beveridge, M., Jarrold C., Pettit, E. (2002). An experimental approach to executive fingerprinting in young children. *Infant and Child Development, 11,* 107-123.

Blair, C. (2003). Behavioral inhibition and behavioral activation in young children: Relations with self-regulation and adaptation to preschool in children attending Head Start. *Developmental Psychobiology, 42,* 301-311.

Blair, C., Granger, D., & Razza, R. P. (2005). Cortisol reactivity is positively related to executive function in children attending Head Start. *Child Development, 76*(3), 554-567.

Blair, C. & Peters, R. (2003). Physiological and neurocognitive correlates of adaptive behavior in preschool among children in Head Start. *Developmental Neuropsychology, 24*(1), 479-497.

Blair, C. & Razza, R. P. (2007). Relating effortful control, executive function, and false belief understanding to emerging math and literacy ability in kindergarten. *Child Development, 78*(2), 647-663.

Blair, C. B. & Willoughby, M. T. (2006). *Measuring executive function in young children.* Chapel Hill, NC: The Pennsylvania State University and the University of North Carolina at Chapel Hill.

Blasi, G., Goldberg, T. E., Weickert, T., Das, S., Kohn, P., Zoltick, B., Bertolino, A., Callicott, J. H., Weinberger, D. R., & Mattay, V. S. (2006). Brain regions underlying response inhibition and interference monitoring and suppression. *European Journal of Neuroscience, 23*, 1658-1664.

Brophy, M., Taylor, E., & Hughes, C. (2002). To go or not to go: Inhibitory control in "hard to manage" children. *Infant and Child Development, 11*, 125-140.

Brocki, K. C., & Bohlin, G. (2004). Executive functions in children aged 6 to 13: A dimensional and developmental study. *Developmental Neuropsychology, 26*(5), 571-593.

Buckner, J. C., Mezzacappa, E., & Beardslee, W. R. (2003). Characteristics of resilient youths living in poverty: The role of self-regulatory processes. *Development and Psychopathology, 15*, 139-162.

Bull, R. & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, switching, and working memory. *Developmental Neuropsychology, 19*(3), 273-293.

Caprara, G. V., Barbaranelli, C., Pastorelli, C., Bandura, A., & Zimbardo, P. G. (2000). Prosocial foundations of children's academic achievement. *Psychological Science, 11*(4), 302-306.

Carlson, S. M. & Wang, T. S. (2007). Inhibitory control and emotion regulation in preschool children. *Cognitive Development, 22,* 489-510.

Chein, J. M. & Schneider, W. (2005). Neuroimaging studies of practice-related change: fMRI and meta-analytic evidence of a domain-general control network for learning. *Cognitive Brain Research, 25*, 607-623.

Cooper, D. H., & Farran, D. C. (1988). Behavioral risk factors in kindergarten. *Early Childhood Research Quarterly, 3,* 1-19.

Cooper, D. H., & Speece, D. L. (1988). A novel methodology for the study of children at risk for school failure. *Journal of Special Education, 22*(2), 186-198.

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia, 44*, 2037-2078.

de Beni, R., Palladino, P., Pazzaglia, F., & Cornoldi, C. (1998). Increases in intrusion errors and working memory deficit of poor comprehenders. *Quarterly Journal of Experimental Psychology, 51A*(2), 305-320.

Deschuyteneer, M. & Vandierendonck, A. (2005). Are "input monitoring" and "response selection" involved in solving simple mental arithmetical sums? *European Journal of Cognitive Psychology, 17*(3), 347-370.

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science, 318,* 1387-1388.

Downer, J. T., Booren, L. M., Lima, O. A., Luckner, A. E., & Pianta, R. C. (*under review*). The Individualized Classroom Assessment Scoring System (inCLASS): Preliminary reliability and validity of a system for observing preschoolers' competence in classroom interactions. Manuscript revised and resubmitted.

Dowsett, S. M. & Livesey, J. (2000). The development of inhibitory control in preschool children: Effecs of "executive skills" training. Developmental Psychobiology, 36, 161-174.

Dunn, L. M., Dunn, L. M., Williams, K. T., & Wang, J. J. (1997). Peabody Picture Vocabulary Test-III. *American Guidance Service, Incorporated.* Pines, MN.

Entwisle, D. E., Alexander, K. L., & Olson, L. S. (1997). *Children, Schools and Inequality*. Boulder, CO: Westview Press.

Espy, K. A., McDiarmid, M. M., Cwik, M. F., Stalets, M. M., Hamby, A., & Senn, T. E. (2004). The contribution of executive functions to emergent mathematic skills in preschool children. *Developmental Neuropsychology, 26*(1), 465-486.

Fantuzzo, J., Perry, M. A., & McDermott, P. (2004). Preschool approaches to learning and their relationship to other relevant classroom competencies for low-income children. *School Psychology Quarterly, 19*(3), 212-230.

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin, 134*(1), 31-60.

Gathercole, S. E., Brown, L., & Pickering, S. J. (2003). Working memory assessments at school entry as longitudinal predictors of National Curriculum attainment levels. *Educational and Child Psychology, 20*(3), 109-122.

Geary, D. C., Hamson, C. O., & Hoard, M. K. (2000). Numerical and arithmetical cognition: A longitudinal study of process and concept deficits in children with learning disability. *Journal of Experimental Child Psychology, 77*, 236-263.

Greenberg, M. T., Kusché, C. A., Cook, E. T., & Quamma, J. P. (1995). Promoting emotional competence in school-aged children: The effects of the PATHS curriculum. *Development and Psychopathology, 7*, 117-36.

Hooper, S. R., Swartz, C. W., Wakely, M. B., de Kruif, R. E. L., & Montgomery, J. W. (2002).Executive functions in elementary school children with and without problems in written expression. Journal of Learning Disabilities, 35(1), 57-68.

Howse, R. B., Calkins, S. D., Anastopoulos, A. D., Keane, S. P., & Shelton, T. L. (2003). Regulatory contributors to children's kindergarten achievement. *Early Education and Development, 14*(1), 101-119.

Howse, R. B., Lange, G., Farran, D. C., & Boyles, C. D. (2003). Motivation and self-regulation as predictors of achievement in economically disadvantaged young children. *Journal of Experimental Education, 71*(2), 151-174.

Hughes, C. & Graham, A. (2002). Measuring executive functions in childhood: Problems and solutions? *Child and Adolescent Mental Health, 7*(3), 131-142.

Kagan, S. L., Moore, E., & Bredekamp, S. (1995). *Reconsidering children's early development and learning: Toward common views and vocabulary*. Washington, D. C.: National Education Goals Panel.

Kerns, K. A. Eso, K., & Thomson, J. (1999). Investigation of a direct intervention for improving attention in young children with ADHD. *Developmental Neuropsychology, 16*(2), 273-295.

Klenberg, L., Korkman, M., & Lahti-Nuuttila, P. (2001). Differential development of attention and executive functions in 3- to 12-year-old Finnish children. *Developmental Neuropsychology, 20*(1), 407-428.

Klingberg, T., Forssberg, H., & Westerberg, H. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology, 24*(6), 781-791.

Klingberg, T. et al. (2005). Computerized training of working memory in children with ADHD—A randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry, 44*(2), 177-186.

Kline, R. B. (2005). *Principles and practice of structural equation modeling (2nd Ed)*. New York, NY: Guilford Press.

Korkman, M. (2000). Executive functions in children: Assessment, development, and disorders. *Revue de Neuropsychologie, 10*(3), 471-487.

Lee, V. E., Brooks-Gunn, J., Schnur, E., & Liaw, F. R. (1990). Are Head Start effects sustained? A longitudinal follow-up comparison of disadvantaged children attending Head Start, no preschool, and other preschool programs. *Child Development, 61,* 495-507.

Lee, K., Ng, S. F., Ng, E. L., & Lim, Z. Y. (2004). Working memory and literacy as predictors of performance on algebraic word problems. *Journal of Experimental Child Psychology, 89,* 140-158.

Lonigan, C. J., Bloomfield, B. G., Anthony, J. L., Bacon, K. D., Phillips, B. M., & Samwel, C. S. (1999). Relations among emergent literacy skills, behavior problems, and social competence in preschool children from low- and middle-income backgrounds. *Topics in Early Childhood Special Education, 19*(1), 40-53.

Luu, P. & Tucker, D. M. (2002). Self-regulation and the executive functions: Electrophysiological clues. In A. Zani& A. M. Proverbio (Eds.) *The Cognitive Electrophysiology of Mind and Brain.* San Diego: Academic Press.

Luu, P., Tucker, D. M., & Stripling, R. (2007). Neural mechanisms for learning actions in context. *Brain Research, 1179,* 89-105.

Marcon, R. A. (2002). Moving up the grades: Relationship between preschool model and later school success. *Early Childhood Research and Practice, 4*(1). *Retrieved 2/20/2009 from http://ecrp.uiuc.edu/v4n1/marcon.html.*

Mazzocco, M. M. M. & Kover, S. T. (2007).A longitudinal assessment of executive function skills and their association with math performance. *Child Neuropsychology, 13,* 18-45.

McCartney, K., Burchinal, M. R., & Bub, K. L. (2006). Best practices in quantitative methods for developmentalists. Monographs of the Society for Research in Child Development, 71(3, Serial No. 285).

McClelland, M. M., Morrison, F. J., & Holmes, D. L. (2000). Children at risk for early academic problems: The role of learning-related social skills. *Early Childhood Research Quarterly, 15*(3)*,* 307-329.

McDermott, P.A, Angelo, L., Waterman, C., & Gross, K. (2005). *Building IRT scales for maximum sensitivity to learning growth patterns over multiple short intervals over time.* Unpublished manuscript, University of Pennsylvania.

McDermott, P. A., Green, L. F., Francis, J. M., & Stott, D. H. (2000). *Preschool Learning Behavior Scale.* Philadelphia: Edumetric and Clinical Science.

McWayne, C. M., Fantuzzo, J. W., & McDermott, P. A. (2004). Preschool competency in context: An investigation of the unique contribution of child competencies to early academic success. *Developmental Psychology, 40*(4), 633-645.

Meade, E. R. (1981). Impulse control and cognitive functioning in lower- and middle-SES children: A developmental study. *Merrill-Palmer Quarterly, 27*(3), 271-285.

Miller, E. K. & Cohen, J. D. (2001).An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*, 167-202.

Montgomery, J. W., Magimairaj, B. M., O'Malley, M. H. (2008). Role of working memory in typically developing children's complex sentence comprehension. *Journal of Psycholinguistics Research, 37*, 331-354.

Muthen, L. K. & Muthen, B. O. (1998). *Mplus Version 4.6.* Los Angeles, CA: Muthen & Muthen.

Nelson, C. A. (2000). Neural plasticity and human development: The role of early experience in sculpting memory systems. *Developmental Science, 3*(2), 115-136.

Nigg, J. T., Quamma, J. P., Greenberg, M. T., & Kusche, C. A. (1999). A two-year longitudinal study of neuropsychological and cognitive performance in relation to behavioral problems and competencies in elementary school children. *Journal of Abnormal Child Psychology, 27*(1), 51-63.

Noble, K. G., Norman, M. F., & Farah, M. J. (2005). Neurocognitive correlates of socioeconomic status in kindergarten children. *Developmental Science, 8*(1), 74-87.

Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry, 37*(1), 51-87.

Posner, M. I., DiGirolamo, G. J., & Fernandez-Duque, D. (1997). Brain mechanisms of cognitive skills. *Consciousness and Cognition, 6*, 267-290.

Prabhakaran, V., Rypma, B., & Gabrieli, J. D. E. (2001). Neural substrates of mathematical reasoning: A functional magnetic resonance imaging study of neocortical activation during performance of the Necessary Arithmetic Operations Test. *Neuropsychology, 15*(1), 115-127.

Riggs, N. R., Blair, C. B., & Greenberg, M. T. (2003). Concurrent and 2-year longitudinal relations between executive function and the behavior of 1st and 2nd grade children. *Child Neuropsychology, 9*(4), 267-276.

Riccio, C. A., Hall, J., Morgan, A., Hynd, G. W., Gonzalez, J. J., & Marshall, R. M. (1994). Executive functions and the Wisconsin Card Sorting Test: Relationship with behavioral ratings and cognitive ability. *Developmental Neuropsychology, 10*(3), 215-229.

Ridderinkhof, K. R., van den Wildenberg, W. P. M., Segalowitz, S. J, Carter, C. S. (2004). Neurocognitive mechanisms of cognitive control: The role of prefrontal cortex in action selection, response inhibition, performance monitoring, and reward-based learning. *Brain and Cognition,56*(2), 129-140.

Riggs, N. R., Greenberg, M. T., Kusche, C. A., & Pentz, M. A. (2006). The meditational role of neurocognition in the behavioral outcomes of a social-emotional prevention program in elementary school students: Effects of the PATHS curriculum. *Prevention Science, 7*(1), 91-102.

Rueda, M. R., Rothbart, M. K., McCandliss, B. D., Saccomanno, L., & Posner, M. I. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences, 102*(41), 14931-14936.

Salthouse, T. A., & Davis, H. P. (2006). Organization of cognitive abilities and neuropsychological variables across the lifespan. *Developmental Review, 26*, 31-54.

Schaefer, B. A., & McDermott, P. A. (1999). Learning behavior and intelligence as explanations for children's scholastic achievement. *Journal of School Psychology, 37*(3)*,* 299-313.

Schonfeld, A. M., Paley, B., Frankel, F., & O’Connor, M. J. (2006). Executive functioning predicts social skills following prenatal alcohol exposure. *Child Neuropsychology, 12*, 439-452.

St. Clair-Thompson, H. L. & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *Quarterly Journal of Experimental Psychology, 59*(4), 745-759.

Stipek, D. (2006). No Child Left Behind comes to preschool. *Elementary School Journal, 106*(5), 455-465.

Title 45 Code of Federal Regulations. (2005). Program performance standards for the operation of Head Start programs by grantee and delegate agencies. Section 1304, 119 - 145.

Vitiello, V. E., Dominguez E., X., Maier, M. F., Fuccillo, J. M., & Greenfield, D. B. (*in preparation*). Individual differences in Head Start children’s school readiness.

Vitiello, V. E., Dominguez E., X., Greenfield, D. B, Fuccillo, J. M., & Maier, M. F. (*under review*). Relationship of executive functions to longitudinal reading and math achievement.

Vitiello, V. E., Munis, P. E., George, J. (*under review*). The role of cognitive flexibility in regulating preschooler's approaches to learning.

Wiebe, S. A., Espy, K. A., & Charak, D. (2008). Using confirmatory factor analysis to understand executive control in preschool children I: Latent structure. *Developmental Psychology, 44*(2), 575-587.

Yen, C. J., Konold, T. R., & McDermott, P. A. (2004). Does learning behavior augment cognitive ability as an indicator of academic achievement? *Journal of School Psychology, 42,* 157-169.

Zigler, E. & Finn-Stevenson, M. (2007). From research to policy and practice: The school of the 21st century. *American Journal of Orthopsychiatry, 77*(2), 175-181.

Table 1

Descriptive Analyses (Means, Standard Deviations, Skew, and Kurtosis) for all Study Variables

	Mean	*SD*	Skew (skew/*SD*)	Kurtosis (kurtosis/ *SD*)	Transformation
Executive Functions[a]					
Spatial Conflict	.643	*.320*	-3.16	-2.63	natural log
Pig Game	.658	*.366*	-4.34	-2.50	natural log
Silly Sounds Game	.584	*.246*	-2.56	-1.13	--
Something's the Same	.584	*.213*	.09	-1.36	--
Pick the Picture	.629	*.204*	-6.11	2.42	natural log
Operation Span	.515	*.198*	-2.39	1.14	--
Preschool Learning Behaviors Scale[b]					
Competence Motivation	48.17	*10.48*	-2.37	-2.39	--
Attention/Persistence	49.35	*10.46*	-3.16	-1.71	natural log
Attitude Toward Learning	51.02	*10.64*	-7.00	6.21	inverse
inCLASS Task Orientation[c]					
Engagement	4.86	*.83*	-3.31	4.36	natural log
Self-Reliance	3.59	*1.12*	-.52	-1.49	--
Behavior Control	5.37	*.88*	-2.37	.58	--
Learning Express[d]					
Fall Vocabulary	183.72	*45.82*	1.69	-1.31	--
Fall Math	188.07	*42.91*	1.58	1.31	--
Fall Listening Comp.	194.43	*45.13*	-5.75	1.79	inverse
Fall Alphabet	181.65	*49.33*	-.80	-.65	--
Spring Vocabulary	217.34	*39.41*	-4.37	2.04	natural log
Spring Math	220.72	*44.13*	-2.40	.34	--
Spring Listening Comp.	218.06	*33.70*	-8.97	21.83	inverse
Spring Alphabet	223.25	*42.53*	-4.42	2.82	natural log
Verbal Ability[e]	82.90	*13.69*	-.57	-.16	--

Notes: [a] Scored as percent correct
[b] Standardized to have a mean of 50 and a standard deviation of 10
[c] Rated on a scale of 1 to 7, with higher scores representing better skills or behavior
[d] Standardized to have a mean of 200 and a standard deviation of 50
[e] Standardized to have a mean of 100 and a standard deviation of 15

Table 2

Correlations between Study Variables

	1	2	3	4	5	6	7	8	9	10	11
1. Age (months)	-										
2. EF - Spatial Conflict	.279**	-									
3. EF - Pig Game	.174*	.219**	-								
4. EF - Silly Sounds Game	-.009	.011	.166*	-							
5. EF - Something's the Same	.199**	.183*	.264**	.220**	-						
6. EF - Pick the Picture	.283**	.287**	.302**	.273**	.363**	-					
7. EF - Operation Span	.127	.056	.093	.088	.267**	.145	-				
8. PLBS – Comp.Motivation	.058	.149*	.134	.080	.118	.191*	.239**	-			
9. PLBS – Attention /Persistence	.074	.125	.175*	.057	.103	.216**	.237**	.777**	-		
10. PLBS - Attitude Toward Learning	.092	.135	.102	.052	.047	.168*	.143	.636**	.775**	-	
11. inCLASS - Engagement	.293**	.219**	.198*	.082	.230**	.250**	.245**	.260**	.292**	.314**	-
12. inCLASS - Self-Reliance	.079	.069	.087	.071	.078	.122	.154	.333**	.246**	.119	.397**
13. inCLASS - Behavior Control	.092	.073	.022	.021	.225**	.187*	.090	.254**	.398**	.441**	.546**
14. LE - Vocabulary (fall)	.341**	.366**	.279**	.065	.244**	.331**	.192*	.228**	.248**	.165*	.309**
15. LE - Math (fall)	.372**	.360**	.332**	.140	.358**	.319**	.186*	.250**	.254**	.152*	.263**
16. LE - Listening Comprehension (fall)	.267**	.397**	.269**	.251**	.242**	.372**	.223**	.206**	.201**	.199**	.352**
17. LE - Alphabet (fall)	.261**	.371**	.256**	.167*	.333**	.294**	.197**	.249**	.216**	.127	.238**
18. LE - Vocabulary (spring)	.310**	.346**	.281**	.018	.244**	.260**	.251**	.226**	.200**	.095	.249**
19. LE - Math (spring)	.447**	.395**	.232**	.098	.288**	.400**	.245**	.406**	.314**	.268**	.338**
20. LE - Listening Comprehension (spring)	.276**	.312**	.268**	.329**	.185*	.366**	.256**	.320**	.290**	.277**	.342**
21. LE - Alphabet (spring)	.273**	.297**	.088	.065	.173*	.263**	.207**	.362**	.268**	.142	.234**
22. Verbal Ability	-.069	.224**	.277**	.165*	.180*	.205**	.149	.253**	.173*	.081	.138

	12	13	14	15	16	17	18	19	20	21
1. Age (months)										
2. EF - Spatial Conflict										
3. EF - Pig Game										
4. EF - Silly Sounds Game										
5. EF - Something's the Same										
6. EF - Pick the Picture										
7. EF - Operation Span										
8. PLBS - Competence Motivation										
9. PLBS – Attention /Persistence										
10. PLBS - Attitude Toward Learning										
11. inCLASS - Engagement										
12. inCLASS - Self-Reliance	-									
13. inCLASS - Behavior Control	.161*	-								
14. LE - Vocabulary (fall)	.185*	.306**	-							
15. LE - Math (fall)	.117	.187*	.574**	-						
16. LE - Listening Comprehension (fall)	.156*	.251**	.589**	.476**	-					
17. LE - Alphabet (fall)	.068	.153*	.626**	.654**	.629**	-				
18. LE - Vocabulary (spring)	.122	.277**	.716**	.542**	.485**	.518**	-			
19. LE - Math (spring)	.208**	.221**	.516**	.712**	.466**	.577**	.516**	-		
20. LE - Listening Comprehension (spring)	.178*	.275**	.460**	.436**	.511**	.457**	.421**	.482**	-	
21. LE - Alphabet (spring)	.102	.166*	.459**	.559**	.413**	.655**	.417**	.666**	.343**	-
22. Verbal Ability	.150	.145	.630**	.446**	.436**	.519**	.553**	.384**	.347**	.400**

* $p < .05$
** $p < .01$
*** $p < .001$

Table 3

Exploratory Factor Analysis of the Executive Functions Data (with Varimax Rotation)

	Factor 1: General Executive Functions	Factor 2: Operation Span/ Working Memory
Spatial Conflict	**.441**	.024
Pig Game	**.475**	-.014
Silly Sounds Game	.318	-.145
Something's the Same	**.543**	-.374
Pick the Picture	**.686**	-.178
Operation Span	.045	**-.716**

Table 4

Exploratory Factor Analysis of the Approaches to Learning Data (with Varimax Rotation)

	Factor 1: ATL - Teacher	Factor 2: ATL - Observed
Competence motivation	**.757**	.254
Attention/persistence	**.912**	.194
Attitude toward learning	**.836**	.180
Engagement	.107	**1.005**
Self reliance	.084	.251
Behavior control	.323	**.398**

Table 5

Hypothesis 1: Relationship between Executive Functions and School Readiness

	Unstandardized Estimate	Standard Error	Standardized Estimate
Factor Loadings			
Executive Functions (EF)			
Pig Game[a]	1.000	--	.456
Spatial Conflict	1.146***	.241	.525
Something's the Same	.997***	.223	.460
Pick the Picture	1.162***	.244	.531
Path Estimates			
Spring Vocabulary (R^2 = .584)			
EF	.584**	.189	.267
Fall Vocabulary	.447***	.079	.444
Verbal Ability	.170**	.065	.172
Sex	-.180[†]	.100	-.090
Spring Math (R^2 = .603)			
EF	1.233***	.314	.587
Fall Math	.260**	.095	.270
Verbal Ability	.489***	.058	.495
Ethnicity	.375*	.158	.171
Spring Listening Comp. (R^2 = .412)			
EF	1.055***	.274	.486
Fall Listening Comp.	.210*	.089	.211
Sex	.328**	.120	.165
Ethnicity	.387*	.161	.171
Spring Alphabet (R^2 = .443)			
Fall Alphabet	.637***	.055	.644
Ethnicity	.399**	.127	.178
EF (R^2 = .627)			
Verbal Ability	.221***	.047	.490
Age	.052***	.010	.552
Ethnicity	-.335***	.092	-.322
WM (R^2 = .049)			
Verbal Ability	.179*	.074	.182
Age	.028[†]	.015	.137
Fall Vocabulary (R^2 = .549)			
Verbal Ability	.649***	.050	.659
Age	.077***	.010	.373
Fall Math (R^2 = .382)			
Verbal Ability	.489***	.058	.495
Age	.082***	.012	.396
Fall Listening Comp. (R^2 = .312)			
Verbal Ability	.468***	.061	.476
Age	.060***	.013	.292
Ethnicity	-.250*	.125	-.110
Fall Alphabet (R^2 = .373)			
Verbal Ability	.545***	.059	.554
Age	.059***	.012	.288

Residual Variances			
EF	.078**	.029	.373
WM	.948***	.101	.951
Spring Vocabulary	.417***	.046	.416
Spring Math	.367***	.048	.397
Spring Listening Comp.	.578***	.067	.588
Spring Alphabet	.541***	.058	.557
Fall Vocabulary	.447***	.048	.451
Fall Math	.616***	.066	.618
Fall Listening Comp.	.681***	.073	.688
Fall Alphabet	.622***	.067	.627
Spatial Conflict	.722***	.081	.725
Pig Game	.797***	.089	.792
Something's the Same	.775***	.086	.789
Pick the Picture	.720***	.084	.718
Correlations			
EF – Fall Vocabulary	.047**	.022	.103
EF – Fall Math	.122***	.033	.267
EF – Fall Listening Comp.	.103***	.031	.227
EF – Fall Alphabet	.113***	.030	.249
Fall Vocabulary – Fall Math	.118**	.041	.119
Fall Vocabulary – Fall Listening Comp.	.172***	.044	.173
Fall Vocabulary – Fall Alphabet	.170***	.042	.171
Fall Math – Fall Listening Comp.	.139**	.050	.140
Fall Math – Fall Alphabet	.279***	.052	.280
Fall Listening Comp – Fall Alphabet	.291***	.054	.294
Spring Alphabet – Spring Math	.211***	.040	.223

Note: [a]*Used to set the metric of the latent variable; no unstandardized estimate or standard error were calculated.*

† $p < .10$

* $p < .05$

** $p < .01$

*** $p < .001$

Table 6

Hypothesis 2: Relationship between Executive Functions and Approaches to Learning

	Unstandardized Estimate	Standard Error	Standardized Estimate
Factor Loadings			
Executive Functions (EF)			
Pig Game[a]	1.000	--	.511
Spatial Conflict	.888***	.210	.452
Something's the Same	1.027***	.219	.522
Pick the Picture	1.162***	.234	.591
ATL – Teacher			
Competence Motivation[a]	1.000	--	.801
Attention/Persistence	1.186***	.087	.963
Attitude toward Learning	.986***	.082	.797
ATL – Observed			
Engagement[a]	1.000	--	.826
Behavior Control	.783***	.167	.647
Path Estimates			
EF (R^2 = .560)			
Verbal Ability	.220***	.052	.430
Age	.052***	.011	.494
Sex	.205*	.088	.202
Ethnicity	-.369***	.105	-.318
WM (R^2 = .041)			
Verbal Ability	.159*	.076	.158
Age	.029[†]	.015	.139
ATL - Teacher (R^2 = .155)			
EF	.512**	.175	.326
WM	.118[†]	.061	.148
Ethnicity	.362*	.153	.199
ATL – Observed (R^2 = .345)			
EF	.885***	.237	.545
Sex	.309*	.138	.187
Ethnicity	.379*	.178	.202
Residual Variances			
ATL – Teacher	.538***	.088	.845
ATL - Observed	.446***	.132	.655
EF	.114**	.041	.440
WM	.957***	.102	.959
Competence Motivation	.356***	.049	.358
Attention/Persistence	.070[†]	.040	.073
Attitude toward Learning	.357***	.046	.365
Engagement	.318*	.139	.318
Behavior Control	.581***	.101	.582
Spatial Conflict	.794***	.092	.796
Pig Game	.732***	.089	.739
Something's the Same	.726***	.088	.727
Pick the Picture	.649***	.086	.651
Correlations			

ATL-Teacher – ATL-Observed	.129*	.058	.196
EF – WM	.093*	.042	.183
Behavior Control – Attn/Persistence	.125**	.042	.128
Behavior Control – Attitude	.181***	.049	.183
Behavior Control – Pig Game	-.110†	.057	-.110
Behavior Control – Something's the Same	.126*	.057	.126
Engagement – Attn/Persistence	-.083†	.049	-.084

Note: [a]*Used to set the metric of the latent variable; no unstandardized estimate or standard error were calculated.*

† $p < .10$

* $p < .05$

** $p < .01$

*** $p < .001$

Table 7

Hypothesis 3: Relationship between Approaches to Learning and School Readiness

	Unstandardized Estimate	Standard Error	Standardized Estimate
Factor Loadings			
ATL – Teacher			
Competence Motivation[a]	1.000	--	1.000
Attention/Persistence	.752***	.047	.769
Attitude toward Learning	.607***	.057	.618
ATL – Observed			
Engagement[a]	1.000	--	.921
Behavior Control	.576**	.136	.545
Path Estimates			
Spring Vocabulary (R^2 = .556)			
Fall Vocabulary	.487***	.076	.485
Verbal Ability	.268***	.070	.272
Age	.034**	.012	.165
Spring Math (R^2 = .591)			
ATL – Teacher	.244***	.049	.253
Fall Math	.444***	.057	.458
Verbal Ability	.147**	.057	.154
Age	.059***	.011	.294
Spring Listening Comp. (R^2 = .373)			
ATL – Teacher	.195**	.062	.197
Fall Listening Comp.	.328***	.072	.330
Verbal Ability	.159*	.069	.163
Age	.042**	.013	.206
Sex	.371**	.119	.188
Spring Alphabet (R^2 = .486)			
ATL – Teacher	.174**	.056	.178
Fall Alphabet	.479***	.065	.490
Verbal Ability	.118†	.065	.123
Age	.031**	.012	.154
Ethnicity	.388***	.115	.174
ATL – Teacher (R^2 = .103)			
Verbal Ability	.248***	.071	.252
Ethnicity	.473**	.159	.207
ATL – Observed (R^2 = .198)			
Verbal Ability	.154*	.071	.171
Age	.057***	.015	.304
Sex	.509***	.134	.278
Fall Vocabulary (R^2 = .547)			
Verbal Ability	.645***	.050	.657
Age	.077***	.010	.373
Fall Math (R^2 = .390)			
Verbal Ability	.475***	.058	.486
Age	.082***	.012	.399
Sex	.175†	.105	.088
Fall Listening Comp. (R^2 = .320)			

Verbal Ability	.472***	.060	.483
Age	.060***	.013	.293
Ethnicity	-.241*	.124	-.107
Fall Alphabet (R^2 = .380)			
Verbal Ability	.550***	.058	.560
Age	.059***	.012	.287
Residual Variances			
ATL—Teacher	.896***	.096	.897
ATL—Observed	.670***	.186	.802
Spring Vocabulary	.444***	.048	.444
Spring Math	.380***	.041	.409
Spring Listening Comp.	.610***	.065	.627
Spring Alphabet	.491***	.053	.514
Fall Vocabulary	.450***	.049	.453
Fall Math	.603***	.065	.610
Fall Listening Comp.	.669***	.070	.680
Fall Alphabet	.617***	.066	.620
Competence Motivation	.000	.000	.000
Attention/Persistence	.391***	.042	.408
Attitude toward Learning	.595***	.064	.618
Engagement	.150	.174	.152
Behavior Control	.657***	.095	.703
Correlations			
ATL-Teacher – ATL Observed	.205**	.069	.225
ATL-Observed—Fall Listening Comp.	.122**	.051	.134
Fall Vocabulary—Fall Math	.116**	.041	.117
Fall Vocabulary – Fall Listening Comp.	.160***	.043	.162
Fall Vocabulary – Fall Alphabet	.168***	.042	.168
Fall Math – Fall Listening Comp.	.130**	.049	.131
Fall Math – Fall Alphabet	.272***	.051	.274
Fall Listening Comp – Fall Alphabet	.282***	.053	.285
Spring Alphabet – Spring Math	.168***	.036	.178
Behavior Control—Attn/Persistence	.148***	.042	.157
Behavior Control— Attitude toward Learning	.199***	.053	.209
Attn/Persistence— Attitude toward Learning	.280***	.042	.291

Note: [a]*Used to set the metric of the latent variable; no unstandardized estimate or standard error were calculated.*

† $p < .10$

* $p < .05$

** $p < .01$

*** $p < .001$

Table 8

Hypothesis 4: Relationship between Executive Functions, Approaches to Learning, and School Readiness

	Unstandardized Estimate	Standard Error	Standardized Estimate
Factor Loadings			
Executive Functions (EF)			
Pig Game[a]	1.000	--	.475
Spatial Conflict	1.091***	.231	.521
Something's the Same	.958***	.213	.461
Pick the Picture	1.162***	.235	.554
ATL – Teacher			
Competence Motivation[a]	1.000	--	.832
Attention/Persistence	1.111***	.076	.832
Attitude toward Learning	.971***	.077	.816
ATL – Observed			
Engagement[a]	1.000	--	.749
Behavior Control	.956***	.170	.719
Path Estimates			
Executive Functions (EF) (R^2 = .604)			
Verbal Ability	.241***	.049	.512
Age	.052***	.010	.528
Sex	.118†	.072	.124
Ethnicity	-.263**	.087	-.242
ATL – Teacher (R^2 = .133)			
EF	.622***	.182	.353
Ethnicity	.421**	.156	.220
ATL – Observed (R^2 = .303)			
EF	.787***	.218	.502
Sex	.286*	.131	.192
Ethnicity	.305*	.155	.180
Spring Vocabulary (R^2 = .585)			
EF	.600**	.196	.286
Fall Vocabulary	.439***	.082	.437
Verbal Ability	.158*	.067	.160
Sex	-.223*	.106	-.112
Spring Math (R^2 = .617)			
EF	.683**	.226	.330
ATL – Teacher	.202**	.065	.173
Fall Math	.353***	.073	.357
Age	.031*	.012	.153
Spring Listening Comp. (R^2 = .420)			
EF	.856***	.254	.410
ATL – Teacher	.188**	.080	.158
Fall Listening Comp.	.194*	.091	.195
Sex	.226†	.129	.113
Spring Alphabet (R^2 = .475)			
ATL – Teacher	.168*	.070	.144

Fall Alphabet	.508***	.065	.517
Verbal Ability	.094	.061	.097
Age	.029*	.012	.143
Ethnicity	.313**	.117	.140
Fall Vocabulary (R^2 = .551)			
Verbal Ability	.651***	.050	.661
Age	.077***	.010	.373
Fall Math (R^2 = .391)			
Verbal Ability	.480***	.058	.488
Age	.082***	.012	.399
Sex	.174†	.105	.087
Fall Listening Comp. (R^2 = .311)			
Verbal Ability	.467***	.061	.474
Age	.060***	.013	.292
Ethnicity	-.252*	.125	-.111
Fall Alphabet (R^2 = .372)			
Verbal Ability	.545***	.059	.553
Age	.059***	.012	.287
Residual Variances			
EF	.090**	.033	.396
ATL—Teacher	.611***	.095	.867
ATL—Observed	.399***	.095	.697
Spring Vocabulary	.415***	.047	.415
Spring Math	.371***	.043	.385
Spring Listening Comp.	.574***	.066	.580
Spring Alphabet	.505***	.055	.525
Fall Vocabulary	.445***	.048	.449
Fall Math	.603***	.065	.609
Fall Listening Comp.	.683***	.073	.689
Fall Alphabet	.624***	.067	.628
Spatial Conflict	.724***	.083	.728
Pig Game	.777***	.088	.774
Something's the Same	.772***	.087	.788
Pick the Picture	.693***	.083	.693
Competence Motivation	.312***	.044	.307
Attention/Persistence	.120**	.036	.121
Attitude toward Learning	.334***	.044	.335
Engagement	.435***	.102	.439
Behavior Control	.476***	.098	.483
Correlations			
EF—Fall Vocabulary	.053*	.024	.111
EF—Fall Math	.111***	.032	.235
EF—Fall Listening Comprehension	.118***	.034	.248
EF—Fall Alphabet	.103***	.031	.217
ATL-Teacher – ATL Observed	.207***	.058	.331
Fall Vocabulary—Fall Math	.113**	.041	.114
Fall Vocabulary – Fall Listening Comp.	.173***	.044	.174
Fall Vocabulary – Fall Alphabet	.170***	.042	.172
Fall Math – Fall Listening Comp.	.135**	.050	.136
Fall Math – Fall Alphabet	.274***	.051	.276
Fall Listening Comp – Fall Alphabet	.293***	.054	.295

Spring Alphabet – Spring Math	.185***	.037	.192
Behavior Control— Competence Motivation	-.097*	.040	-.097

Note: [a]*Used to set the metric of the latent variable; no unstandardized estimate or standard error were calculated.*

[†] $p < .10$

* $p < .05$

** $p < .01$

*** $p < .001$

Figures

Figure 1. Confirmatory factor analysis model for the executive functions variables.

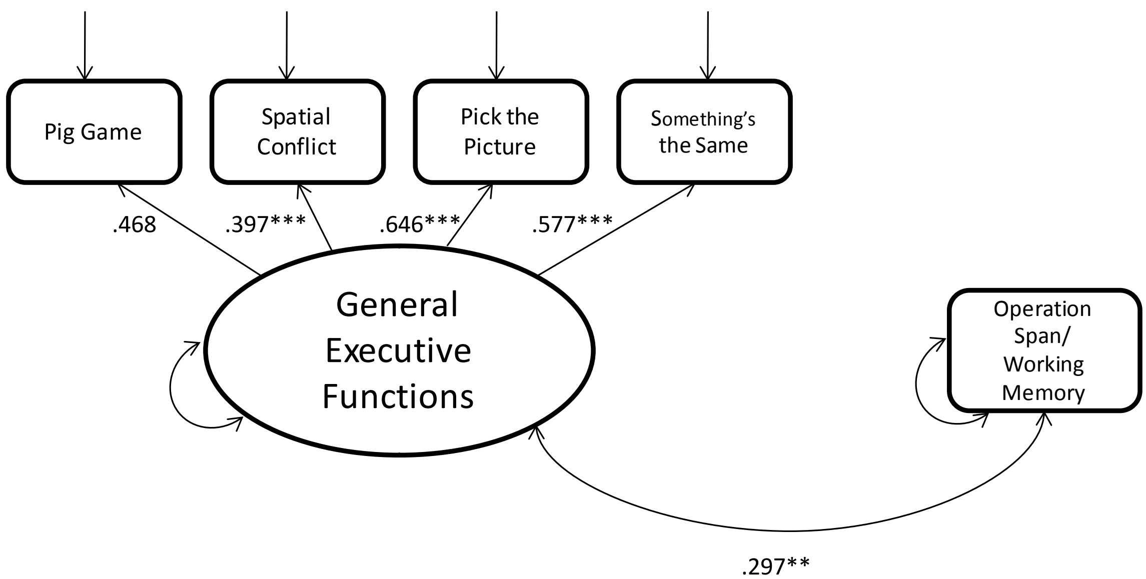

Figure 2. Confirmatory factor analysis model for the approaches to learning variables.

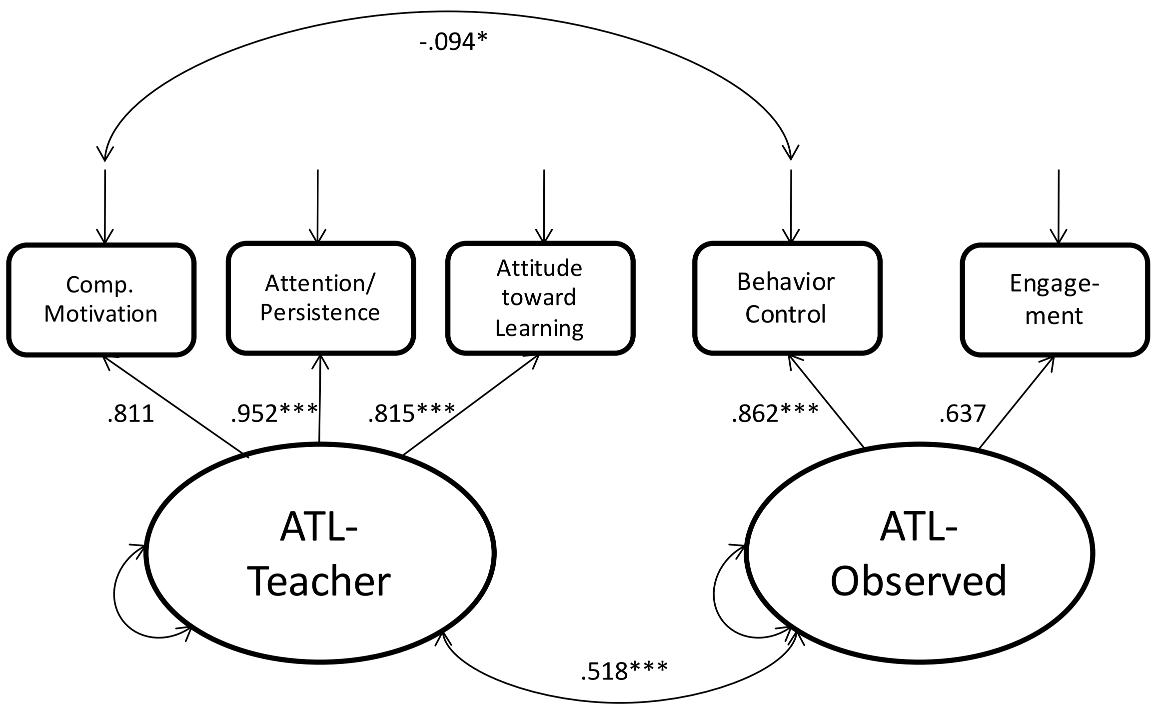

*Figure 3.*Simplified model showing standardized relationships between executive functions and school readiness. Covariates (age, sex, ethnicity, and verbal ability) are partialled out of all variables where significant.

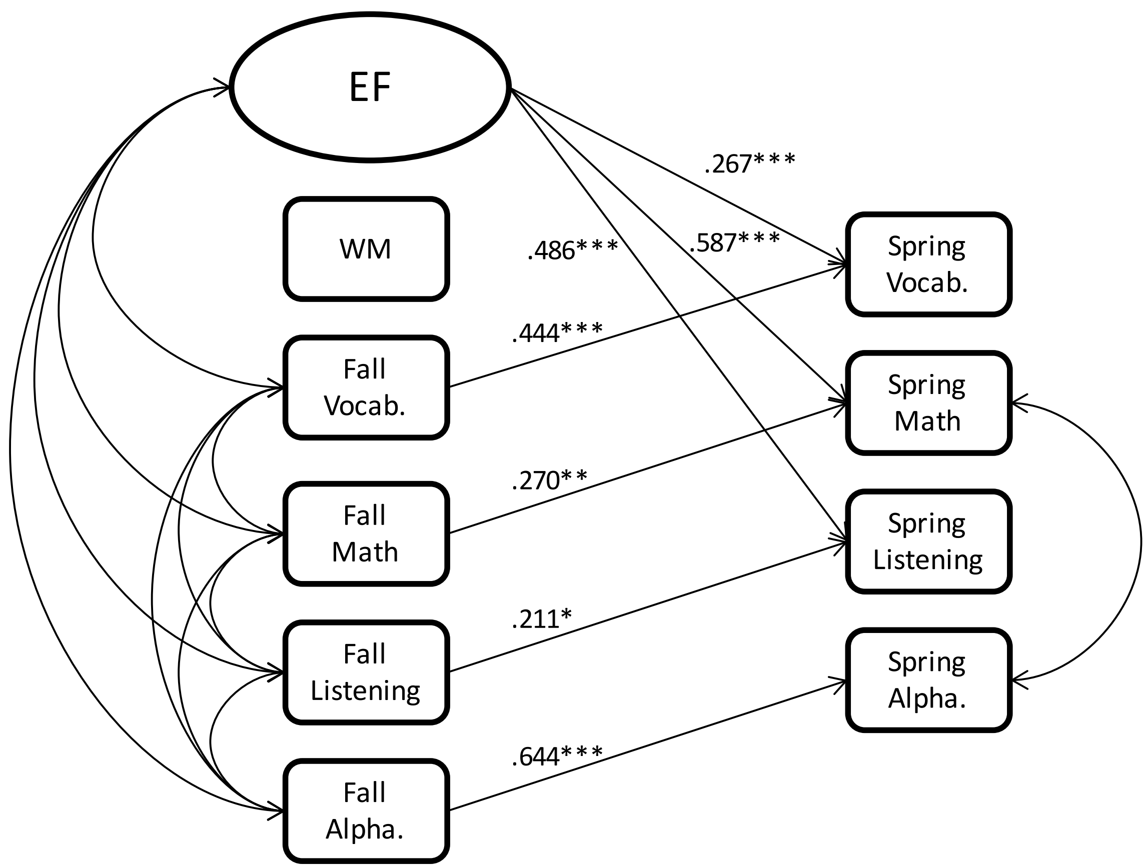

Figure 4. Simplified model showing standardized relationships between executive functions and approaches to learning. Covariates (age, sex, ethnicity, and verbal ability) are partialled out of all variables where significant.

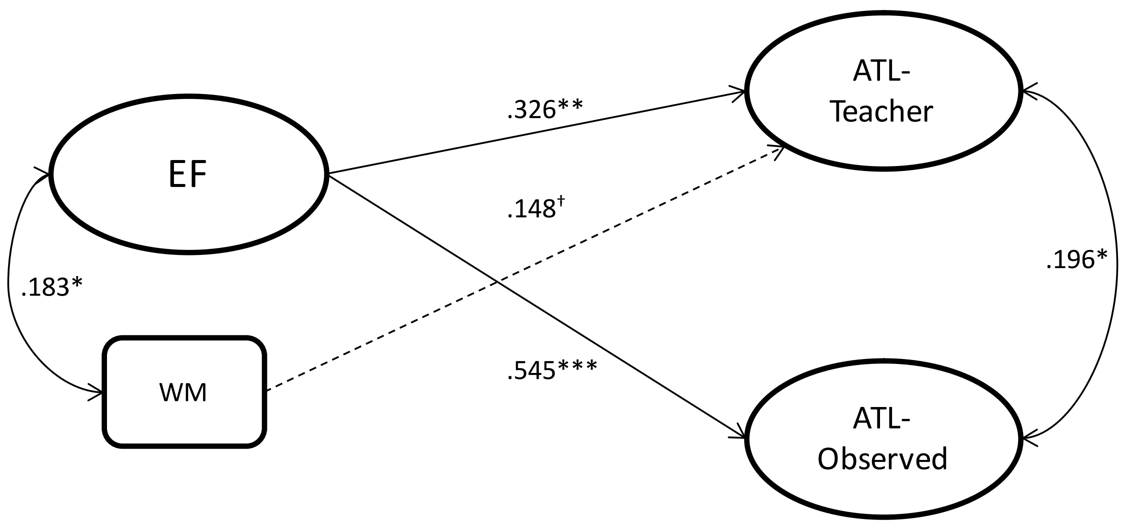

Figure 5. Simplified model showing standardized relationships between approaches to learning and school readiness. Covariates (age, sex, ethnicity, and verbal ability) are partialled out of all variables where significant.

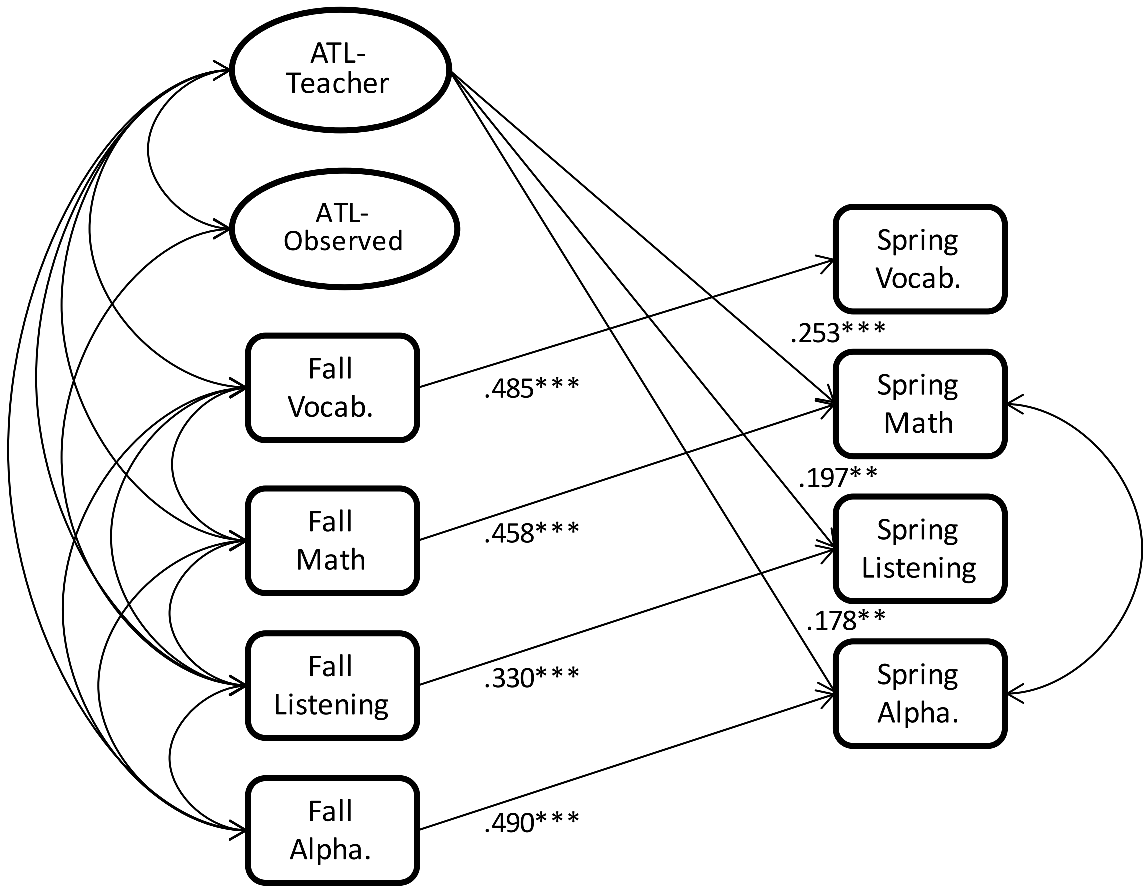

Figure 6. Simplified model showing standardized relationships between executive functions, approaches to learning, and school readiness. Covariates (age, sex, ethnicity, and verbal ability) are partialled out of all variables where significant.