Predicting Early Academic Achievement: An Investigation of the Contribution of Executive Function

PREDICTING EARLY ACADEMIC ACHIEVEMENT: AN INVESTIGATION OF

THE CONTRIBUTION OF EXECUTIVE FUNCTION

by

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DEDICATION

This dissertation is dedicated to Jean Walter.

"Until the very end." –J.K. Rowling

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ABSTRACT

This study investigated the important question of whether pupils' executive functions (EF) predict early academic achievement. Current conceptualizations suggest that developmental trends in EF can be measured in young children and that EF may play an important role in predicting academic achievement and school readiness. To date, however, there is little empirical support for this assertion. This study explored EF skills of 3- to 5 year-olds using the Dimensional Change Card Sort Task (DCCS). The first objective was to determine if EF indeed predicts math, reading, and writing achievement in 3- to 5-year-olds. The second objective was to determine if EF's prediction of academics occurs independent of the contribution made by general ability (e.g., Battelle motor and language subdomains). The third objective was to determine if the contribution of EF remains uniform across the age span. Consequently, existing data from 969 participants between 54 to 71 months was used. This consisted of scores on the DCCS as well as the Phonological Awareness Literacy Screening (PALS) to measure early reading and writing skills, the Test of Early Math Ability -Third Edition (TEMA-3) to measure early math skills, and sections of the Battelle Developmental Inventory 2nd Edition (BDI-2) to measure general development. A positive relationship between EF and early math, reading, and writing skills was found. Also EF, as measured by the DCCS, contributed a significant portion of variance in early math, reading, and writing skills after accounting for general development, age, and socioeconomic status. Finally, the contribution of EF to early reading and writing skills remained stable between 3 and 5 years old. In contrast, EF was a stronger predictor of early math skills among 3-year-olds when compared to 5-year-olds.

CHAPTER 1

INTRODUCTION

This chapter provides an overview of the major concepts addressed in the current study: executive function (EF) and school readiness. First, the popularity and relevance of EF is discussed. Second, the concept of school readiness and its importance is discussed. The chapter ends with a discussion of the importance of examining emerging EF skills as a signal of school readiness.

The Concept of Executive Function

All around us, EF has become an important area for study and debate. From peer-reviewed journals to articles in Times Magazine, EF has become a buzzword for both the psychological community and the general public. Within the field of psychology, the surge of interest in EF can be seen from research to practice. Descriptions of EF have been found everywhere from psychoeducational reports to various workshops available for psychologists and educators. Research in the area of EF is expanding in all directions to include a variety of age groups and areas of disability. Generally, all are curious about how EF could be helpful in understanding psychological disorders as well as how that knowledge can be used to create effective interventions.

EF refers to "higher-order, self-regulatory cognitive processes that aid in the monitoring and control of thought and action" (Zelazo, Carlson, & Kesek, 2008). EF is an umbrella term for all the skills necessary for adaptive, goal-directed behavior including several core processes such as: response inhibition, planning, sustained attention, organization, shifting, inhibition, emotional regulation, and working memory (Fisher, DeLuca, & Rourke, 1997; Romine et al., 2004). EF is associated with the prefrontal

cortex, which holds the important function of regulating both thought and behavior through the activation and inhibition of other brain areas (Garon, Bryson, & Smith, 2008).

One of the reasons for the popularity of EF is that EF skills are necessary for successful performance in real life situations. It allows people to problem solve, assessing and adjusting to unexpected situations, as well as manage everyday stressors. These skills help individuals to regulate behavior in order to reach a goal. For example, EF allows a person to think about consequences before they act, to manage emotions in order to complete a task, and to behave in a flexible manner in accord with current circumstances. A person with impairment in EF may experience difficulty with working memory, task initiation, or impulse control. This impairment may impact job performance, tasks of everyday living, or social interactions. EF deficits are frequently associated with a number of psychological disorders including depression (McDermott & Ebmeier, 2009), bipolar disorder (Dixon, Kravariti, Frith, Murray, & McGuire, 2004; Mur, Portella, Martinez-Aran, Pifarre, Vieta, 2007), impulse control disorders such as pathological gambling (Roca, Torralva, Lopez, Cetkovich, Clark, & Manes, 2008) and schizophrenia (Hutton, Puri, Duncan, Robbins, Barnes, & Joyce, 1998).

The skills associated with EF are evident even in young children and infants. An infant's ability to search for a hidden object is one example of task requiring the use of EF. The infant must think of the hidden object while performing the task of searching (Zelazo, 2003). As EF continues to develop through childhood, the skills become more complex and include organization, planning, working memory, and other higher order thinking skills (Dawson & Guare, 2004).

Neurodevelopmental disorders such as autism, attention deficit hyperactivity disorder (ADHD), and Tourette's syndrome have also been linked to EF (Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; Kenworthy, Yerys, Anthony, & Wallace, 2008; Pennington & Ozonoff, 1996). EF is also appearing in the research literature regarding children impacted with other conditions such as anxiety disorders, mood disorders, conduct disorder, as well as learning disabilities (Romine et al., 2004).

EF is an important skill in many areas, but is especially important for academic success. Recent research has found a correlation between EF and academic achievement (Bull & Scerif, 2001; Romine et al., 2004; St. Clair-Thompson & Gatherole, 2009; Taylor, Schatschneider, Petrill, Barry, & Owens, 1996) and early school success (Blair & Razza, 2007; Brock, Rimm-Kaufman, Nathanson & Grimm, 2009; Espy et al., 2004; McClelland et al., 2007). One example of how EF impacts the reading process follows.

EF aids in reading comprehension by permitting a student's continual monitoring, evaluating and revising the meaning of the text (Kucer, 2005). EF is also necessary for selecting reading strategies. Semrud-Clikeman (2005) explained that children must be able to self-monitor while they are reading and correct mistakes. The ability to ask, "how am I doing?" during a task and make the necessary adjustments is crucial during the reading process. Semrud-Clikeman (2005) discussed some interesting uses of EF tasks as screening tools. She recommended that besides the screening instruments typically used to identify children who may be at risk for learning disabilities, screening instruments of neuropsychological constructs such as working memory, attention, or inhibition should also be included. Others, such as Romine et al. (2004), conclude that EF deficits may not be unique to a specific disorder, but instead are a characteristic of clinical populations in

general. Whether part of a specific diagnostic battery or a screening tool, given the

overwhelming interest in EF and the large number of predictors for later success, an EF

measurement is worth including. One area of particular interest related to the use of EF

screening tools is in the area of school readiness.

Hot and Cool EF

EF is considered a domain general cognitive function, but a distinction is still

made between affective-motivational aspects of the task (Beck, Schaefer, & Carlson,

2011; Zelazo & Muller, 2002). Tasks that involve controlling emotional arousal, the

presence of extrinsic rewards, or delayed gratification are all examples of "hot" EF. An

example of a hot EF task would be the Children's Gambling Task (Kerr & Zelazo, 2004).

In contrast, cool EF tasks are emotionally neutral, abstract, generally involve working

memory and flexible rule use, and more commonly thought to be traditional information

processing or problem solving tasks (Hongwanishkul, Happaney, Lee, & Zelazo, 2005).

In fact, research has shown there to be an overlap between "cool" EF and intelligence (as

measured by standardized tests (Duncan et al., 2000, Hongwanishkul et al., 2005). An

example of a cool EF task would be the Dimensional Change Card Sort task (DCCS;

Frye, Zelazo, & Palfai, 1995; Zelazo, 2006). There also difference in brain activation for

hot and cool EF tasks. Cool EF tasks are associated with the dorsolateral and

ventrolateral prefrontal cortex, while hot EF tasks activate the orbitofrontal cortex (Beck,

Schaefer, & Carlson, 2011; Happaney, Zelazo, & Stuss, 2004). While there is some

debate as to which EF tasks are considered hot versus cool (Garon, Bryson, & Smith,

2008), it is important to note that EF tasks range in the extent they feature implicit (cool)

versus extrinsic (hot) motivation (Metcalfe & Mischel, 1999). Also, it is important to

keep in mind that both the cool cognitive and the hot emotional subsystems are all part of one interactive system that work together in any situation (Happaney, Zelazo, & Stuss, 2004; Hongwanishkul et al., 2005; Metcale & Mischel, 1999). For the purposes of this study, the focus will be on cool EF as related to tasks such as attention, shifting, and response inhibition.

The Concept of School Readiness

Ensuring that all children are ready to learn at school entry remains an important preoccupation in the United States and abroad. In 1990, The National Education Goals Panel (NEGP) declared school readiness as a goal to prepare all children for school success (Kagan, et al., 1995). The NEGP inspired a wave of research related to various aspects of school readiness and the impact of school readiness on later school achievement. School readiness can be defined as the mastery of specific, basic skills observable at school entry that are necessary for later school success (Hair, Halle, Terry-Humen, Lavelle, & Calkins, 2006; Snow, 2006). In general, school readiness can be thought of as how prepared children are to function successfully in the school environment. This overview of school readiness provides a description of the construct of school readiness and describes the importance of school readiness as a predictive tool that might help close an achievement gap (e.g., between rich and impoverished students).

School readiness is a multidimensional construct that involves many levels of influence including family, community, and school (Blair, 2002; Snow, 2006). The goals presented by the NEGP focus on a broad, holistic view of what it means to be prepared for school and include five domains: physical health, well-being and motor development, social and emotional development, approaches to learning, language and literacy

development, and cognition and general knowledge (Kagan et al., 1995). This multifaceted construct of school readiness emphasizes the idea that there is not just one special skill that all children need to know before they enter school. Instead, the child with well-developed skills in a variety of domains will be better prepared for school. Each domain brings with it its own area of research, expertise and intervention and in order to reach the goal that children will be ready to enter school (Kagan et al., 1995). Ideally, all five domains should be the focus of research as a way to encourage healthy development and devise early intervention plans. It is recommended that young children be monitored in all five areas so that that early intervention in any or several domains can take place if necessary.

There is predictive power in specific dimensions of school readiness. For example, emergent literacy and numeracy skills as well as attention-related skills have been shown to be strong predictors for later academic achievement (Duncan et al., 2007). Within the domain of cognition and general knowledge, Blair (2001) found that intellectual ability at kindergarten predicted grade retention in early elementary school. A review of the literature confirms that cognitive ability or intellectual ability accounts for a large proportion of the variance in school achievement (Finkelman, Ferrarese, & Garmezy, 1989; Hamlett & Pellegrini, 1987; Huffman, Mehlinger, & Kerivan, 2000).

Deficits in school readiness could result in later academic delays. Early academic weaknesses have the potential to impact children's efficacy and motivation, crucial factors to later school success (Clark, Pritchard, & Woodward, 2010). With the potential negative impact of early school delays in mind, the research then turns to early educational remediation, with a particular focus on the remediation of delays in school

readiness often experienced by at-risk children from low socioeconomic backgrounds (Welsh, Nix, Blair, Bierman, & Nelson, 2010). The response has been programs such as Head Start and other prekindergarten programs that can be structured with the intent to close the substantial achievement gaps found between middle-income and low-income children prior to school entry. The goal of such programs is to enrich and foster development in key areas so as to close the achievement gap. It is arguably crucial to close this gap at a young age because the achievement gap only continues to widen as children continue their schooling and this deficit in school readiness contributes to significant disparities in learning outcomes, and long term employment potential later in life (Duncan et al., 2007).

In order to effectively provide early intervention, researchers are now charged with examining exactly which cognitive processes that develop during early childhood correlate with school readiness and the successful acquisition of pre-academic skills. With specific cognitive processes and early academic skills highlighted, practitioners will then be able to identify early deficits and intervene as necessary. Such interventions may lead to higher levels of school readiness and later school achievement.

Although the focus of school readiness literature has been on emergent literacy and numeracy skills, perhaps the early detection and remediation of emergent executive skills is equally important. In his article describing a developmental neurobiological model of school readiness, Blair (2002) speculated that indicators of self-regulation (including EF) are both independent and strong predictors of school readiness. Early detection of delays in developing EF is important for two main reasons. First, substantial portions of EF skills are beginning to develop during this important pre-K window.

Second, the cognitive processes that EF encompasses provide a solid background of skills necessary for early school success. The following section gives a closer examination of the two main reasons for the importance of early detection of delays in EF.

First, EF abilities show dramatic growth across the preschool period (Carlson et al, 2004; Hughes & Ensor, 2007, 2011). Clark, Pritchard, and Woodward (2010) commented on the rapid changes that occur in EF during the preschool years. They observed that the preschool years are a very sensitive time for changes in EF, including the development of skills such as planning, set shifting, and inhibitory control. They stated that this sensitive period of growth is also a time when individual differences emerge and are measurable. Clark, Pritchard, and Woodward comment that these emerging individual differences in EF skills are likely to begin to shape individual learning trajectories. During the preschool period, the core components of EF develop, forming the critical foundation that will set the stage for later growth of higher cognitive processes (Garon, Bryson, & Smith, 2008).

The second reason that detecting executive deficits during early childhood is important is that EF provides a foundation for all learning to take place. The transition to kindergarten can be especially problematic for children who have not mastered basic regulatory skills associated with EF such as paying attention, following instructions, and inhibiting inappropriate behaviors (McClelland et al., 2007). As children transition from infancy to elementary school age, they are increasingly in situations where they must regulate their behavior appropriately in a variety of contexts both at school and at home (Espy et al., 2004). Regulatory skills such as strategy selection during cognitive tasks and regulating attention are associated with successful school adjustment (Blair, 2002).

For many children, preschool is the first time they are expected to follow a set of rules, regulate their emotions, problem solve, and sit quietly and attentively while learning something new. In a survey of a nationally representative sample of kindergarten teachers reported that over one-half of the children in their classroom lacked the skills and behaviors necessary to function appropriately in the classroom (Rimm-Kaufmann, Pianta, & Cox, 2000). Consequently, it can be argued that there is a need for early identification and intervention in the area of EF so that all children possess the skills necessary to be engaged and benefit from the classroom environment.

A better understanding of EF and school readiness is the first step to early detection and potentially intervention to change a child's school trajectory. The following chapter explores the literature on EF development in younger children and its impact on early academic achievement.

CHAPTER 2

REVIEW OF THE LITERATURE

In order to better understand the contribution of EF in predicting early academic performance, it is important to take a closer at construct of EF as well as the current research exploring higher order cognitive processes and school readiness in young children. This chapter is focused on the developmental properties of EF and the tools used to measure EF skills in young children. The remainder of the chapter critically reviews the literature regarding the connection between EF and academic achievement for both school age and younger children.

Developmental Properties of EF

Historically, EF studies have focused on the adult population. Given that the population of interest in the current study is young children, this section allows the reader to gain an understanding of the developmental properties of EF, including neurological evidence for the developmental of EF during childhood.

Previously, it was assumed that all EF skills developed during adolescence concurrently with the development of the prefrontal cortex, but research has shown evidence for the development of these cognitive skills starting at a young age. In fact, some EF skills start developing in infancy, and many show rapid rates of development during the preschool years; some areas develop well into adolescence and early adulthood (Davidson, Amso, Anderson, & Diamond, 2006; Hughes & Ensor, 2011; Zelazo, 2003).

One reason for the misconception that EF develops during adolescence is that until recently there were no developmentally appropriate measures of EF for children younger than 10 years of age (Welsh, Pennington, & Grossier, 1991). The typical EF

tasks administered to adults were too difficult for young children (Hughes & Ensor, 2011). Over the past decade, however, measures of EF have been adapted and developed for use with young children. With the increase of new, child-friendly EF tasks in the past few decades, developmental EF research has grown exponentially (Hughes & Ensor, 2011). As researchers turned to study EF among younger age groups, there grew a complication in the type of tasks typically used to measure EF.

There are still some concerns with child-friendly measures of EF. One such concern is that when EF tasks are simplified with the purpose of being developmentally appropriate for young children, the critical EF component may be lost (Garon, Bryson, & Smith, 2008). Another concern is that the many EF tasks have weak psychometric properties (Bishop, Aamodt-Leep, Creswell, McGurk, & Skuse, 2001; Hughes & Ensor, 2011). Especially during the transitional period surrounding preschool when many skills are rapidly developing, it is difficult to isolate EF factors during testing from the many other non-EF factors.

Development of EF and the prefrontal cortex. EF, a higher cognitive ability, is especially dependent upon functioning of an intact and adequately developed prefrontal cortex (PFC). Background information about the PFC provides a better understanding of both the development of EF and the type of tasks used to measure EF. The PFC is associated with processing information related to rule use, particularly rules governing behavior (Bunge & Zelazo, 2006; Wood & Grafman, 2003). Wood and Grafman's review of neuroimaging and anatomical studies present an explanation from a structural standpoint as to why humans are capable of abstract thoughts and behaviors, as well as integrates input from several sources. The specialized, anatomical features of the PFC

make EF possible. For example, the neurons in the PFC have the special ability to fire over extended periods of time and across events. Lesion studies in monkeys have shown a significant decrease in performance on a delayed-response task after a lesion to the PFC, which identifies the specific location needed to support EF (Levy & Goldman-Rakie, 2000). At a cellular level, the specialized neurons in the PFC have a sustained firing level when compared to other cells. For example, on an auditory delayed-response task in monkeys, 68 out of 138 neurons showed a significantly different firing rate from the baseline measurement (Bodner, Kroger, & Fuster, 1996). Also, the cells in the PFC are more slender and pointed than other cells in the brain, which suggests that they are better able to handle several excitatory inputs at once (Fuster, Bodner, & Kroger, 2000). These specially equipped neurons are able to support the cognitive processes necessary to accomplish long-term goals (Wood & Grafman, 2003). These studies provide a structural explanation for why people are able to engage in goal-orientated behaviors (Wood & Grafman, 2003).

Most knowledge about EF was acquired from neuroimaging studies and clinical studies of adults who have suffered brain injuries or lesions to the PFC. Extensive research with adult subjects using the Wisconsin Card Sorting Test (WCST), a widely used method to measure EF skills such as cognitive shifting, provides support for the involvement of the PFC in EF skills. In the WCST, participants need to switch between a variety of rules based on the cards features such as shape, number, and color and the feedback of the experimenter. Research has shown that patients with damage in the PFC perseverate on the previous rule set despite feedback from the examiner (Milner, 1963; Moriguchi & Hiraki, 2009). Those with damage in the PFC had difficulty with the

flexible shifting of mental sets. A variety of neuroimaging studies using the WCST and other measures of EF have continued to support the hypothesis that the PFC plays an important role in flexible shifting between mental sets (Barcelo & Knight, 2002; Hampshire & Owen 2006; Konishi et al., 1998; Monchi et al., 2001; Wood & Grafman, 2003). Specifically, a group of six patients with focal lesions in their lateral PFC displayed abnormally high rates of perseverative errors on the WCST compared to 8 matched control subjects. The authors argued that this finding is indicative of difficulty in set shifting associated with damage to the PFC. Moreover, the effect size of 0.82 found in this study is large enough to make such an EF deficit meaningful in the lives of affected individuals (Barcelo & Knight, 2002).

Similar evidence indicating frontal activation during EF tasks was provided by Konishi and colleagues (1998). They capitalized on the temporal resolution ability of functional magnetic resonance imaging (fMRI) that takes two 2 seconds per slice of the brain's activity during tasks. Using this technique, seven normal adult subjects revealed activation in the posterior part of both the right and left inferior frontal sulci during the set-shifting component of the WCST.

Like their adult counterparts, young children with PFC damage experience difficulty with inhibition, self-regulation, cognitive shifting and perseveration of responses (Brooks, et al., 2003; Moriguchi & Hiraki, 2009). Consequently, the development of the PFC may actually begin at a much younger age than previously thought (Welsh, Pennington, & Grossier, 1991). Regarding methodology, researchers began with studies of younger children using adult measures of EF and then began developing new tools designed for children. Many of the adult tasks for EF were

modified in order to test the same skill set in children. For example, on the DCCS, children experience difficulty with the flexible shifting of mental sets. The DCCS is similar to the WCST in that they both require cards to be sorted first by one dimension and then a different dimension, but the DCCS differs in that the child is told the rules before each trial (Hongwanishkul, Happaney, Lee, & Zelazo, 2005). Research shows that 3-year-olds perseverate to the first rule 60% percent of the time, whereas 4-year-olds are able to sort cards according to the second rule 90% of the time (Zelazo, Frye, & Rapus, 1996). Importantly, DCCS perseverate errors in 3-year-olds are quite similar to adult patients with prefrontal damage on the WCST, urging developmental researchers to assume that tasks that the PFC plays an important role in the flexible shifting of mental sets (Bunge & Zelazo, 2006; Moriguchi & Hiraki, 2009; Zelazo, 2006).

Moriguchi and Hiraki (2009) confirmed that the PFC is activated in young children during a cognitive shifting task (the DCCS) in a neuroimaging study using near-infrared spectroscopy (NIRS). NIRS is a noninvasive technique that measures changes in blood flow in the brain. Similar to those discussed above, the 3-year-old subjects displayed perseverative errors during the post-switch phase of the DCCS, whereas both 5-year-olds and adults were able to pass both phases. The NIRS results indicated that both the 5-year-old group and the adults displayed activation in the inferior PFC, although those 3-year-olds with perseverative errors did not show activation in the PFC. These results support the assumption that the inferior PFC contributes to cognitive shifting in young children and that the PFC may be responsible for perseverative responses (Moriguchi & Hiraki 2009). Thus, it appears that the preschool periods mark a

period of development in the cortical regions of the brain responsible for EF (Kerr &

Zelazo, 2004).

Measuring EF in Children using the DCCS Task

The preschool years can be described as a critical transition period characterized

by rapid developmental changes in a variety of areas including memory skills, emotional

regulation, and goal directed behavior (Espy et al., 1999). A clear conceptualization of

EF during this period of rapid change is crucial for accurate identification of children

with deficits in EF (Diamond, Barnett, Thomas, & Munro, 2007). One tool for measuring

EF in preschool children is the DCCS (Frye, Zelazo, & Palfai, 1995; Zelazo, 2006). The

DCCS is the tool used to measure EF in the current study. The following section provides

a description of the DCCS, describes the theory underlying the DCCS, and reports the

reliability and validity of the DCCS.

Description of the DCCS. The DCCS is a widely used measure of EF known

because of the ease of administration and its usefulness in assessing important changes in

EF that occur between the ages of 3- and 5-years-old (Carlson, 2003; Hongwanishkul,

Happaney, Lee, & Zelazo, 2005; Zelazo, 2006; Zelazo & Müller, 2010). The DCCS

specifically measures rule-use, inhibition, and cognitive shifting (Zelazo, 2003). All

versions of the DCCS involve the use of two target bivalent test cards (such as a blue

rabbit and a red boat). The DCCS then uses two sorting phases: "pre-switch" and "post-

switch." During the pre-switch phase the child is asked to sort a series of cards based on

one dimension (e.g., color). Then during the post-switch phase, the child is asked to sort

according to the other dimension (e.g., shape) (Zelazo, 2006). Performance is typically

measured by how many cards the child is able to sort correctly during the post-switch

phase. Because results typically form a bimodal distribution, Zelazo (2006) suggested using a pass/fail scoring procedure. Participants are scored as passed if they correctly answer five out of the six post-switch trials correctly. For the border stage, a passing score was correctly answering 9 or more out of 12 trials. There are several versions of the DCCS. The standard version of the DCCS is suitable for children from 2.5- to 5-years-old and the border version is geared toward children from 5- to 7-years old who passed the integration task. The following section will describe several versions of the DCCS. This will allow the reader to understand the background of the test that ultimately created the study version.

Versions of the DCCS. The original version, developed by Zelazo and colleagues (1995), is a tabletop test that includes two levels: integrated and border. The differences between the various levels is subtle, but effective in extending the floor and ceiling which allows for a more accurate scores for both younger and older children.

In the integrated level, the participants are first presented with test cards of two different shapes (e.g., a star or a truck) and two different colors (e.g., blue or red; see Figure 1). The participants are then given a third card (e.g., a blue truck) and asked to sort it first by matching one of the existing cards on one dimension (color). After six trials of sorting by color, they are asked to match the cards on the other dimension (shape). All participants start with a demonstration and two sample trials before starting the integrated level. Testing ends when the child fails a level (a score of 4 or less on the post-switch phase). There are 12 trials in the integrated phase (six pre-switch and six post-switch) and 12 trials of the border stage. The directions and the rule for sorting are stated before each

trial. For example, "Play the color game: If it's red, it goes here; but if its blue, it goes there. Here's a blue one. Where does it go?" (Zelazo, 2006).
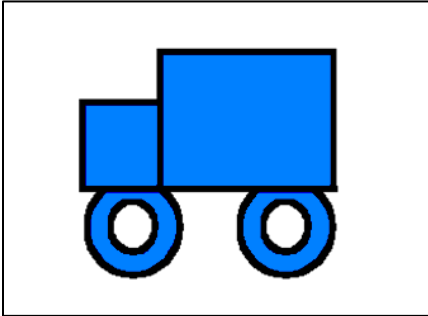
Figure 1. Sample card integrated level (blue truck with white background).

In the Border Level, the cards are identical to those used in the integrated stage, but they have a 5 mm black border around them as seen in Figure 2. Children are instructed to play the color game when there is a border on the card and to play the shape game when there is no border.

Figure 2. Sample card border level (red star with white background and dark border).

Diamond, Carlson, and Beck (2005) developed a level to precede the integrated level to address a possible flooring effect for young children. The new level consists of cards that separate the color from the dimension (see Figure 3). The main figure is black with a color in the background. Diamond, Carlson, and Beck (2005) found that when the color was not integrated in the figure itself, three-year-olds were more successful during

the post-switch phase. They hypothesized that when the primary feature of the object is the color; young children find it difficult to see the object from a different perspective and are not able to flip their focus to the shape (Diamond, Carlson, & Beck 2005; Diamond & Kirkham, 2005). With a sample of 57 children ages 2½ to 3½, they found that 3-year-olds passed the separated level three times more than they passed the integrated condition. For 3 year olds the separated level was passed by 44% of the children, while 18% of children passed the integrated level ($p < .03$). For 3 ½ year olds, 63% passed the separated level and 41% passed the integrated level (results not statistically significant due to small sample size). The separated level was administered in the current study to allow for greater variability in scores among 3-year-olds.
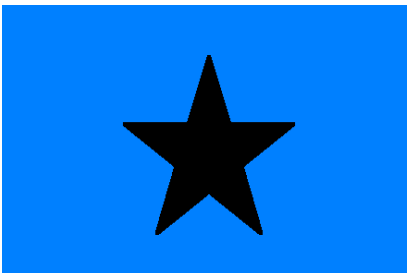
Figure 3. Sample card separated level (black star with blue background).

The Toolbox DCCS, developed for ages 3 through 85, is administered on a computer with a touch screen and has two levels: integrated and mixed. There are four practice items before each level (integrated and mixed) and the levels are administered in four blocks: practice, pre-switch integrated, post-switch integrated, and mixed. The mixed level switches randomly between the pre-switch dimension and the post-switch dimension so that the dimensions are mixed rather than the typical administration of six pre-switch and six post-switch. Instructions appear on the screen and were read aloud for

participants 8-years-old and younger. During the practice block, children are to attain a score of three out of four trials before moving to the next block. Feedback is provided after each trial of the practice block, but no feedback is provided during the other blocks.

Abulic dissociation. The interesting aspect of the standard version of the DCCS is the bimodal distribution of scores. Kindergarten age children (i.e., 5- and 6-year-olds) can successfully sort according to both dimensions, but nearly all 3-and 4-year-olds are able to sort the cards correctly by only the first dimension. While typically developing 4 year olds are likely to continue sorting correctly during the post-switch phase, most 3-year-olds are unsuccessful (e.g. Brooks, Hanauer, Padowska, & Rosman, 2003; Frye et al., 1995; Hanania & Smith, 2010; Kirkham, Cruess & Diamond, 2003; Perner & Lang, 2002; Towse, Redbond, Houston-Price, & Cook, 2000; Zelazo, Frye, & Rapus, 1996). The majority of 3-year-olds continue sorting by the first dimension despite being told the new rules before every item (Hanania, 2010; Zelazo, 2006). In fact, the majority of 3-year-olds perseverate during the post-switch period despite correctly answering questions about the post-switch rules (Zelazo, 2006). This mismatch of words and actions is called Abulic Dissociation (Kirkham, Cruess, & Diamond, 2003).

Theoretical Foundation of the DCCS

The DCCS is based in cognitive complexity and control theory of EF (CCC theory; Zelazo & Frye, 1997). According to CCC theory, during the preschool years children become increasingly aware that more than one rule can apply to the same situation, they are able to find interrelationships among rules, and eventually are able to cognitively represent hierarchical relationships among sets of rules (Brooks et al., 2003). CCC theory describes complexity in terms of the number of levels embedded in a rule

system that children are able to integrate, maintain in their working memory, and use when problem solving (Zelazo & Muller, 2010). For example, the DCCS contains rule pairs (if the card is a boat it goes here) embedded within a higher order system (if we are playing the shape game). According to CCC theory, 3-year-old children are not successful in tasks that include two incompatible rules embedded within a higher order rule (Zelazo & Frye, 1997).

Zelazo, Müller, Frye, and Marcovitch (2003) have since revised CCC Theory to integrate the original CCC theory with the Levels of Consciousness (LOC) Model. In the LOC model, the ability to use complex rules increases as children are able to consciously reflect on the rules they represent. In terms of the DCCS, this means that 3-year-old children keep both the pre-switch rules (shape game) and post-switch rules (color game) at the same level of consciousness. They are successfully able to hold both rules in their memory, but are not able to integrate the two rule systems into one, more complex system. Older children (e.g. 5-year-olds), on the other hand, successfully complete the DCCS task because they have developed a high level of consciousness that allows them to make a deliberate decision to use the correct set of rules appropriately. Overall, CCC theory and the revised theory (CCCr) describe a child's ability for reflection and higher order rule use.

With regard to the perseverative response found among three-year-olds on the DCCS, several theories have been ruled out through task manipulation studies including: difficulty with sorting by shape or color, the use of a preferred category during the pre-switch phase, lack of memory span, and the ability to see both dimensions on the card. Current literature indicates that the perseveration is most likely the result of an interaction

between inhibition, attentional inertia, and cognitive shifting. Due to maturational changes, 3-year-olds have not yet developed the ability to disengage their attention from the pre-switch rules and successfully switch to the post-switch rules.

Psychometric Properties of the DCCS

As previously described, the DCCS is a widely used measure of EF in preschool age children. As an unpublished laboratory test, the DCCS is currently under development with research groups collecting information about the test's reliability and validity. Although the DCCS does not have a technical manual describing its psychometric properties, the current body of literature points to sound psychometric properties including adequate reliability and validity. The evidence of reliability and validity found it the literature will be described below.

Reliability. Test-retest reliability as measured by intraclass correlation coefficients (ICC) points to acceptable reliability values in two studies. In the first study with a sample of 40 children 2.5-4.5 years old, the same day test-retest reliability for the DCCS task was ICC= .94 (Beck, Schaeffer, & Carlson, 2011). Further analysis of each subtask of the DCCS indicated acceptable test-retest reliability (DCCS Separated ICC= .78, DCCS Integrated ICC= .94, DCCS Advanced ICC= .90). They found no significant practice effects on the EF tasks used in this study. Similarly, the test-retest reliability for the Toolbox DCCS was ICC= .92 in a sample of 48 children (Zelazo et al., 2013). Zelazo and colleagues reported no evidence of a practice effect over an average two-week test-retest period (mean practice effect = -.04, p = .83).

Validity.

Age effects. When administered to a large sample of children, the DCCS proved to be sensitive to maturational changes between the ages of 2.5 through 4.5 years. A meta-analysis of the results of studies using the DCCS (total sample is equal to 211 children ages 2.5-4 years) indicates a significant age effect ($p < .001$; Beck, Schaeffer, & Carlson, 2003). Similarly, a moderate to strong correlation ($R^2 = .76$) was found for the DCCS and age in a sample of 174 children ages 3- to 15-years-old (Zelazo et al., 2013).

Construct validity. As outlined by Messick (1995), a test has construct validity if it accurately measures a theoretical construct or trait. The construct validity of a test such as the DCCS is worked out over a period of time on the basis of an accumulation of evidence. One accepted method for establishing a test's construct validity is convergent and divergent validation. As described in more detail below, the DCCS displays adequate validity with its high correlation with other measures of EF.

Convergent validity. To establish construct validity, several studies have compared the DCCS to established measures of the EF construct. For example, several studies have shown acceptable correlations between the DCCS and measures of EF including measures of working memory and inhibition such as the Spin The Pots Task ($r(37) = .47$, $p < .01$; Beck, Schaeffer, & Carlson, 2011). In addition, the standard version of the DCCS correlated with the Self-Ordered Pointing task, a measure of working memory ($r = .50$, $p < .001$; Hongwanishkul, Happaney, Lee, & Zelazo, 2005).

One might also expect to find positive, but weaker correlations between DCCS and general cognitive ability. In fact, the DCCS was positively related to performance IQ ($r = .69$) as measured by the Bead Memory and Pattern Analysis subtests of the Stanford-Binet Intelligence Scale-Fourth Edition (SB-4; Thorndike, Hagen, & Sattler, 1986). To

measure construct validity, the Toolbox DCCS was compared to the Block Design subtest of the Wechsler Preschool and Primary Scale of Intelligence, 3rd Edition (WPPSI-III; Wechsler, 2002), a measure of fluid cognition that is highly correlated with EF (Blair, 2006). For 3-6 year olds, the Toolbox DCCS scores were correlated with the WPPSI-III scores ($r(74) = .69, p < .001$; Zelazo et.al., 2013).

Divergent validity. Zelazo and colleagues predicted that the Toolbox DCCS would demonstrate adequate validity by displaying lower correlations for divergent measures (receptive vocabulary) than convergent measures. To measure discriminant validity, the Toolbox DCCS was compared to the Peabody Picture Vocabulary Test, 4th Edition (PPVT-IV; Dunn & Dunn, 2007). For 3-6 year olds, the DCCS was positively correlated with the PPVT-IV ($r(78) = .79, p <. 001$ and did not significantly differ for the convergent correlation previously described. The DCCS, intended as an index of the development of EF during the preschool years, displays adequate reliability and validity as measured by test-retest reliability and convergent validity studies.

EF and Academic Achievement

EF as a predictor of academic skills has become an area of interest over the past 10 years. The importance of EF skills in academic achievement for elementary students has been established (Alexander, Entwisle, & Dauber, 1993; Bull & Scerif, 2001; Kail, 2003; McClelland, Acock, & Morrison, 2006). Currently, however, researchers aim to extend the age of participants downward to explore the predictive relationship between EF and pre-academic skills in young children. Results from nine studies are reported here, each of which explored the relationship between EF and early academic skills. These studies vary in several ways, including regarding characteristics of participants and

the assessment tools used. For example, some studies examined both early literacy and early math skills, whereas others focused on just one academic skill. The measurement of EF varied from a behavioral questionnaire to a battery of assessment tools used to measure the three main components of EF. The scarcity of research studies on EF in early childhood and achievement provides support for the idea that more studies, including the current one, need to be conducted.

Nonetheless the existing literature generally confirms that EF is a central aspect of cognitive development during the preschool period and that EF skills are an important factor for academic school success. When examining specific academic skills, more studies have concerned the association between EF and early math skills than early reading skills. The following literature review provides support for the importance of EF in early academic skills and provides direction for future studies. Each study is reviewed for its unique contribution to understanding of EF skills and early academic achievement.

In several studies, the predictive relationship of EF was determined by measuring preschool EF skills and then later school outcomes. These prospective studies are important for determining if EF skills in preschool are effective indicators of later school success. The period of time between the initial EF measure and the measure of academic skills varied from one semester to three years depending on the study. The following review first discusses the research related to school achievement and EF in school age children and then focuses on the research available for preschool age children. The section for school age children includes all studies where any or all of the measures are administered to participants six years of age or older. As mentioned above, a review of the current literature revealed that most of the studies concerning EF and achievement are

prospective. The major prospective studies are included in this literature review to describe the history of studies that have been completed and demonstrate the correlation between EF and achievement that has been established. For the purpose of this review, preschool studies are defined as any study including participants 5-years-old or younger.

  EF and school readiness in school age children. The first study reviewed explored the association between early academic, social, and cognitive skills measured at school entry (age 5-6 years) and later school outcomes measured between the ages of 8-14 years by examining data from six longitudinal data sets from the United States, Canada, and Great Britain (Duncan et al., 2007). In their analysis, Duncan et al. included a wide variety of school readiness predictors that have been previously explored in the literature and multiple dimensions of school achievement including grade completion, math and reading achievement, and rating scales filled out by teachers. Of interest to the current study is Duncan et al.'s inclusion of early attention skills as a factor that may influence later academic skills. All six data sets used in the study measured attention skills when participants were between 5 and 6 years old. Attention, as described and measured by Duncan et al., is one of the core processes included within the umbrella of EF. The inclusion of attention skills in this study provides some insight into the importance of early EF skills, although other aspects of EF were not examined.

  Attention skills were consistent predictors of later achievement with an average effect size of 0.10, which was smaller than that of early reading and early math skills. Duncan et al.'s (2007) study provides support for the influence of attention skills on later school success. With the correlation between early attention skills and later school achievement, a logical next step would be to examine the correlation between other

similar cognitive processes also included under the EF umbrella (e.g., inhibition, planning) and school achievement.

In a second study investigating EF and later school success, Pagani, Fitzpatrick, Archambault, and Janosz (2010) sought to replicate Duncan et al.'s 2007 study in Canada with French speaking kindergarteners. Consistent with Duncan et al. (2007), kindergarten math skills, attention abilities, and language skills predicted academic achievement at the end of second grade. Kindergarten attention skills predicted later math and reading skills indicating the potential of attention and its associated cognitive processes (EF) as a predictor for later school success. Kindergarten attention skills significantly predicted second grade math ($r = .25$) and reading ($r = .20$) skills. Interestingly, the regression coefficients are in the same range as those for kindergarten math skills ($r = .23$) and reading skills ($r = .23$). Both Duncan et al. (2007) and Pagani, Fitzpatrick, Archambault, and Janosz (2010) highlighted the importance of attention and EF as part of an early school achievement battery. Both of these studies addressed the development of early cognitive processes through attention and behavior rating scales. In contrast, the following studies used a specific battery of EF skills to measure the main components of EF. In other words, unlike the prior studies, the following studies appear to more fully represent the construct of EF through direct measures.

Although attention was the only component of EF measured in the first two studies, Blair and Razza (2007) measured both the inhibitory control and attention shifting aspects of EF in 170 Head Start students. Blair and Razza (2007) sought to determine the unique contribution of preschool EF to kindergarten math and literacy skills over and above general intelligence. To measure EF, they used a peg-tapping task

to measure inhibitory control and an item-selection task to measure attention shifting. General intelligence was measured with the Peabody Picture Vocabulary Test (PPVT) in preschool and the Raven's Progressive Colored Matrices in kindergarten. Academic achievement was measured in three areas: mathematics knowledge, phonemic awareness, and letter knowledge.

EF, including the specific cognitive processes of inhibitory control and attention shifting, was found to predict later academic achievement. Specifically, separate regression equations were calculated representing the unique effect of each variable on the outcome adjusted for all other terms in the model including general intelligence. Inhibitory control measured both in preschool and in kindergarten made independent contributions to early academic skills. Inhibitory control measured in preschool predicted math skills in kindergarten ($r = .47$, $p < .01$), phonemic awareness ($r = .21$, $p < .05$) and letter knowledge ($r = .18$, $p < .05$). Inhibitory control measured in kindergarten predicted three academic areas: mathematics knowledge ($r = .44$, $p < .01$), phonemic awareness ($r = .35$, $p < .01$), and letter knowledge ($r = .25$, $p < .01$). Attention shifting in preschool predicted early math abilities in kindergarten ($r = .26$, $p < .01$) as well as letter knowledge ($r = .21$, $p < .05$), but not phonemic awareness. In contrast, attention shifting measured in kindergarten predicted all three academic skills: math skills ($r = .42$, $p < .01$), letter knowledge ($r = .32$, $p < .01$), and phonemic awareness ($r = .18$, $p < .05$). This study provides support for the idea that EF, and more specifically inhibitory control and attention shifting, is an important aspect of cognitive development during early childhood that impacts early academic success. The ability to inhibit a tendency to respond despite

distracting stimuli or irrelevant information contributes to emerging academic skills above and beyond specific academic knowledge.

Another prospective study that used preschool EF to predict later math achievement included a sample of 104 preschoolers from New Zealand to examine the relationship between EF at 4-years-old and math skills at 6-years-old (Clark, Pritchard, & Woodward, 2010). This study is important because although several studies have found a correlation between EF and math skills in school age children (Bull & Scerif, 2001; Gathercole & Pickering, 2000; Mazzocco & Kover, 2007; McLean & Hitch, 1999), few have focused on early childhood abilities. The purpose of the Clark study was to determine if the predictive relationship between EF and math skills that had already been found in school age children would extend to younger children and if this relationship would persist even after accounting for both general cognitive ability and concurrent reading ability (Clark, Pritchard, & Woodward, 2010).

The specific executive skills measured in this study included inhibitory control, planning, set shifting, and behavior regulation in the preschool setting. The battery of EF measures included the three-disc version of the Tower of Hanoi (Simon, 1975; Welsh, 1991) to measure complex executive planning, the Flexible Item Selection Task (FIST; Jacques & Zelazo, 2001) to measure set shifting and cognitive flexibility, and Shape School (Espy, 1997) to measure inhibitory control and set shifting as well as the Behavior Rating Inventory of Executive Function-Preschool (BRIEF-P; Gioia, Espy, & Isquith, 2003) completed by preschool teachers. In addition, the short form of the Wechsler Preschool and Primary Scale of Intelligence-Revised (WPPSI-R) was used to measure general cognitive ability. Math achievement was measure at 6-years-old using the math

fluency subtest of the Woodcock-Johnson III Tests of Achievement (WJ-III; Woodcock, McGrew, & Mather, 2001).

The correlations between the various preschool EF measures and the math achievement measures at age 6 were in the moderate range (rs = .18 - .48). When examining the contributions of the various EF tasks, the correlations among the measures of EF were relatively uniform with no single measure providing a unique contribution to the prediction of mathematic achievement. Critically, after accounting for family SES, gender, general IQ, and reading achievement, EF continued to show a unique relationship with later performance on the WJ-III Math Fluency subtest ($t = 2.13, p < .05$). An improved score on one EF measure was associated with a 5 to 10 point advantage in math achievement two years later. EF was at least as predictive as IQ in predicting mathematics ability. The zero order correlation coefficient for IQ and EF was r= -0.63 indicating a strong relationship. This has important implications for practical use as measures of EF are generally very easy to use and quick to administer. Overall, the results indicated that children's performance on EF tasks at age 4 years were clearly associated with children's later performance on standard mathematics achievement tasks at age 6.

Monette, Bigras, and Guay (2011) examined the association between EF and school achievement among kindergarten students in Canada. This longitudinal study investigated the degree to which aspects of EF in kindergarten are associated with school achievement by the end of first grade. Two separate measures of each inhibition, flexibility, and working memory were included in the EF battery. The extensive EF battery included the Backward Word Span, Backward Block Span, Day-Night Test, Fruit

Stroop, Knock-and-Tap, Trail-P, Card Sort, and the Lollipop Test. Of note among the battery of tests, the Card Sort, used to measure cognitive flexibility, is the most similar to the DCCS used in the current study. Factor analysis revealed that the Card Sort loaded on to of the merging factors that the author labeled inhibition and flexibility.

The Card Sort task was indeed significantly correlated with the reading/writing composite ($r = .23$, $p < 0.5$) but not math achievement ($r = .05$). This result is consistent with what would be expected given the literature review above. When measured in preschool, math achievement is correlated to working memory more than other EF factors. As math content becomes more complex in later grades, other aspects of EF such as inhibition and flexibility become more important. Of the three factors, working memory and inhibition showed significant results. Flexibility was not correlated with achievement. The results indicated a moderate effect size for working memory and reading/writing achievement ($rs = .51$) as well as working memory and math achievement ($rs = .46$). Inhibition was also significantly associated reading/writing ($rs = .24$) but effect size was small. Using multiple mediation analysis, only working memory showed a significant direct effect of math achievement ($\beta = .32$, $p < .05$) that accounted for 5% of the variance. Although most studies of school-age children show a strong link between inhibition and math achievement, but this study found a strong link between working memory and math achievement.

The association between EF, specifically working memory and attention, and emerging math and literacy skills was examined in a prospective study of 164 children from Head Start classrooms in Pennsylvania (Welsh, Nix, Blair, Bierman, & Nelson, 2010). With importance of working memory and attention in predicting school

achievement already established (Blair & Razza, 2007; Li-Grining, 2007; McClelland et al., 2007), this study documented an association between the rapid growth in EF skills during the preschool period and early academic achievement in kindergarten. The participants were assessed at three times: the beginning of the preschool year, the end of the preschool year and then finally at the end of the kindergarten year. Emergent literacy skills were measured with three subtests from the Test of Preschool Early Literacy: Print Knowledge, Blending and Elision scale. To measure reading achievement at the end of kindergarten, the following four scales were averaged into a composite score: the Letter-Word Identification and Story Recall subtests from the Woodcock-Johnson III Tests of Achievement (WJ-III; Woodcock, McGrew, & Mather, 2001) and the Sight Word Efficiency Test and the Phonemic Decoding Efficiency Test from the Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999). To measure math achievement, the Applied Problems subtest from the WJ-III was administered. General cognitive abilities associated with learning were assessed with several different measures. The Backward Word Span was used to assess working memory, the Peg Tapping Task to test inhibitory control, and the DCCS to measure cognitive shifting abilities. Following the approach of other researchers measuring similar cognitive skills, Welsh et al. created one composite measure of EF by standardizing and averaging the scores for all three tasks during each assessment period. Researchers have found that at the preschool age, specific skills are not well differentiated and share significant variance (Hughes & Ensor, 2007; Wiebe, Espy, & Charak, 2008).

Due to the importance of language skills during the preschool stage of development, language skills were covaried. The preschool EF composite significantly

predicted both kindergarten reading achievement (*r*= .32 - .52) and kindergarten math achievement (*r* = .39 - .58). After controlling for specific academic skills and language ability, the EF composite did make a unique contribution to both reading and math achievement (β = .36). This study contributed to the body of literature by examining the relationship between growth in EF skills preschool and academic achievement through the end of kindergarten in low-income family students. This study was also unique in that the DCCS, the same measure used in the proposed study, was included in the EF battery.

EF and school readiness in preschool age children. Although, as indicated above, considerable evidence exists for an EF-elementary achievement link, the data are sparse regarding EF and preschool achievement. The remainder of this literature review will focus on the available research exploring EF and early academic skills in preschool children. In a cross-sectional study of EF and school readiness, an EF battery and the measurement of emergent math abilities was administered to 96 preschool children (Espy et al., 2004). The EF battery included measures of working memory, inhibitory control, and cognitive shifting. Both working memory and inhibitory control predicted early math skills after controlling for child age, maternal education, and child vocabulary. When controlling for the other cognitive processes (shifting and working memory) inhibitory control continued to account for 12% of the variance. The correlation between inhibition and early math skills found in this cross-sectional study of preschool children replicated those findings of prospective studies using school age children (Blair & Razza, 2007; Clark, Pritchard, & Woodward, 2010).

Nonetheless, Espy and colleagues found that cognitive shifting did not significantly contribute to math skills in preschool children. This finding is contrary to

findings from studies of EF and math skills in school age children (Bull & Sceriff, 2001; McLean & Hitch, 1999). There are several explanations for the difference in the findings of cognitive shifting found in school age children versus in preschool children. One explanation is that that cognitive shifting might develop later than some of the other EF skills. Consequently, cognitive shifting would be associated with later school achievement but would not register as significant for preschoolers. Another potential explanation is that the cognitive shifting may not be needed in early math skills, but it is needed later, more complicated math skills. A third possible explanation for this unexpected finding may be the level of difficulty of the shifting task Espy and colleagues used. In other words, the shifting task may have been too difficult for preschoolers creating a flooring effect. The scores on the particular shifting task may not have been varied enough to show any true differences among preschoolers. Consequently, it would be beneficial to explore the role of cognitive shifting in early math skills using a different measure of cognitive shifting that might possess greater sensitive to EF status of preschool children. Overall, this study provides evidence that the relationship found between EF and mathematics ability in school age children (Bull & Scerif, 2001; Gathercole & Pickering, 2000; Mazzocco & Kover, 2007; McLean & Hitch, 1999) also exists in a younger age group.

McClelland et al. (2007) sought to examine the association between preschoolers' behavioral regulation and key academic skills. With the focus on inhibitory control, attention, and working memory, the researchers defined behavioral regulation as a broad construct representing skills involved in controlling, directing, and planning emotions, cognitions and behavior. Given this definition, behavioral regulation would be analogous

with EF as it is defined in the current study. This study investigated the predictive

relationship between behavioral regulation and emergent literacy, vocabulary, and math

skills. It has already been established that behavioral regulation is important for

achievement in elementary school, and so McClelland et al. extended the research

downward to the preschool age group to identify when behavioral regulation becomes an

important factor for academic achievement.

They measured 310 middle to upper-middle class young children both in the fall

and spring of their preschool year. The Head-to-Toes Task, a direct observational

measure of inhibitory control, attention, and working memory, was used to measure

behavioral regulation. Key academic skills were measured by the Letter Word

Identification, Picture Vocabulary, and Applied Problems subtests from the Woodcock

Johnson III Tests of Achievement (WJ-III; Woodcock, McGrew, & Mather, 2001) or the

Batería Woodcock Muñoz R (Woodcock & Muñoz-Sandoval, 1996).

With the use of a direct measure of EF instead of the teacher or parent report,

McClelland and colleagues predicted that growth in EF over the school year would be

significantly and positively related to gains in early academic skills. Indeed, EF did

improve significantly from fall to spring semester and was significantly correlated with

all three academic outcomes for both fall and spring semester. Fall and spring EF was

significantly correlated with all three academic outcomes: reading, vocabulary, and math.

The strongest correlation was with EF and math scores in the fall ($r = .47$, $p < .001$) and

spring ($r = .37$, $p < .001$). Literacy was moderately correlated with EF in fall ($r = .25$, $p < .001$) and in spring ($r = .22$, $p < .001$). Finally, vocabulary scores correlated with EF in

the fall ($r = .35$, $p < .001$) and in spring ($r = .30$, $p < .001$). Moreover, using hierarchical

linear modeling to control for age, gender, and language of administration, McClelland and colleagues continued to find a robust relationship between EF and achievement. After controlling for fall achievement, spring EF scores predicted spring academic outcomes in all three areas: reading, vocabulary and math ($p < .05$ in all areas). McClelland et al reported that a one standard deviation gain in EF resulted in a gain of almost 3 weeks of prekindergarten math skills or one month gain of prekindergarten literacy skills with a small effect size ($d = .09$).

Overall, this study provides support that preschool EF is a critical component of school readiness, potentially warranting inclusion in school readiness batteries. That is, assessment of EF might allow for early identification of deficits such as attention, working memory, and inhibitory control. However, future research should include large and diverse samples to provide further validation of the findings that are impossible from the findings of McClelland and colleagues.

Using a significantly larger sample size when compared to the study by McClelland and colleagues, The National Institute of Child Health and Human Development (NICHD) study in 2003 is the largest study of its kind by far; it included 1002 children, all of who were 54 months old at time of enrollment. The role of attention as a mediator between family environment and school readiness was the primary focus of the study. Both the NICHD study and the current study measure inhibition and attention. The current study uses the DCCS to measure inhibition of previous response criteria and attention shifting to the new criteria, whereas the NICHD study used the Continuous Performance Task (CPT) to measure two aspects of attention: inhibition of impulsivity, as measured by the ability to inhibit inappropriate responding, and sustained attention. As

part of the data analysis, hierarchical regression models were used to test the association between the attention measures and the outcome measures, which included measures of cognition, achievement, language and social measures. The NICHD found that the measured attention processes were positively correlated with achievement as well as language and social outcomes for preschool children. The association between the two attention measures (sustained attention and impulsivity) and achievement are of interest to the current study and will be discussed below. Lack of sustained attention, as measured by errors of omission on the CPT, predicted achievement scores (β = -.16) as measured by the Woodcock-Johnson Revised Tests of Achievement (WJ-R; Woodcock & Johnson, 1989). As the number of errors increased, the total achievement score decreased. These results translate to a positive relationship between the construct of sustained attention and achievement. Effect size was found by the squared semi-partial correlation (sr^2 = .023). In other words, about 2% of the unique variance in this model can be explained by sustained attention. As to the other measure of attention, impulsivity, the number of impulsive errors predicted lower scores on achievement (β = -.13, p < .001) with an effect size of .015. Both lack of sustained attention and impulsivity significantly predicted achievement, but effect sizes were quite small when using Cohen's (1969) guide to power analysis.

Summary of literature review, research questions, and hypotheses. An association between EF skills (such as attention shifting and inhibition) and academic achievement in elementary age children has been established. However, critically, the same association has yet to be explored for preschool age children and early academic skills. More specifically, there is a need for more studies using a reliable and valid

measure of EF appropriate for 3-to 5-year olds. In addition, few research studies have included an EF measure of cognitive shifting. And finally, while there are a few studies about early reading and math skills, there are essentially no studies exploring the contribution of EF to early writing skill acquisition. Consequently, this current study is designed to address preschool EF and concurrent achievement.

Research questions and hypotheses. The current study will focus on the following three research questions and the hypotheses associated with them.

Research question one. What is the relationship between EF and early academic skills?

Hypothesis one. There will be a positive relationship between EF and early reading, math, and writing skills (after controlling for age).

Research question two. What, if any, unique variance does EF contribute to predicting early academic skills after accounting for general development?

Hypothesis two. EF will contribute a significant portion of variance (after accounting for general development as well as age and socioeconomic status) in predicting early academic (reading, writing and math) skills.

Research question three. Does the contribution of EF to early academic skills change between the ages of 3-5 years?

Hypothesis three. The contribution EF (controlling for age and general development) to early academic (reading, writing, and math) skills will change between 3-years-old and five-years-old.

CHAPTER 3

METHODOLOGY

This chapter describes the methods utilized in the study, including a description of the participants, materials used, and procedure for data collection. A description of the data analysis plan is also discussed.

Participants

The participants in the present study originally consisted of 3,927 children between 3 and 5 years of age from drawn from a database of 8,167 participants in the First Things First External Evaluation, Longitudinal Child Study of Arizona (LCSA). Participants were recruited from across the state in three general geographical areas: North, Central, and South. A variety of recruitment techniques were utilized including flyers, word of mouth, and notices at preschools, daycare centers, and community events. A graphic representation of the sampling process and exclusionary factors is presented in Figure 4. From the database of 8,167 participants, there were 3,927 young children between the ages of 3 to 5 years old (36 to 71 months). Of those 3,927 participants, 1,796 participants were administered the test measures in Spanish and consequently were excluded from the final analysis. Within the set of participants between the ages of 3 to 5 years who completed the English version of the test measures, 1019 had complete data, with scores for the English version of the DCCS, Phonological Awareness Literacy Screening (PALS), Test of Early Math Ability -Third Edition (TEMA-3) and Battelle Developmental Inventory 2nd Edition (BDI-2). Finally, a total of 50 participants reported a diagnosis of developmental delay (4.6%) and/ or autism (.9%) and were excluded from

the final study. Of the 3,927 participants between the ages of 3-5 years, 1,846 were

excluded from final analysis due to pre-set exclusionary criteria for a total sample size of

969 young children. Given the substantial sample size, it was determined that the sample

was sufficient for the purposes of the study without using missing variable equations.
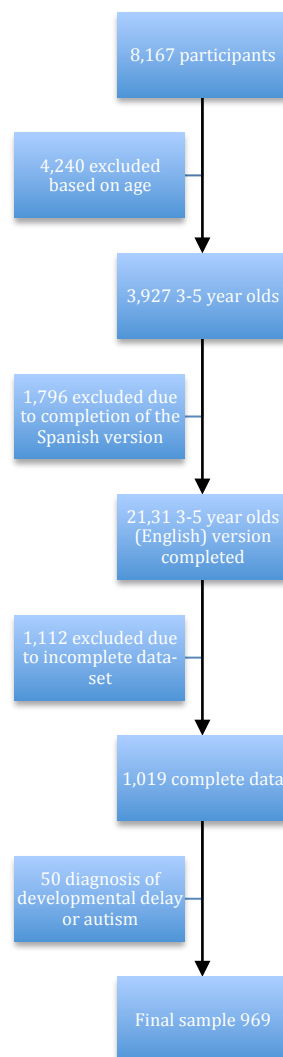
Figure 4. Sampling of participants and exclusionary criteria used in the current study.

Materials

    Instruments. The following measures were used in the current study.

Phonological Awareness Literacy Screening (PALS-PreK; Invernizzi, Sullivan, Meier, & Swank, 2004). As part of the early academic skills variable, emergent reading and writing skills were measured with the Alphabet Knowledge, Name Writing, and Rhyme Awareness subtests of the PALS-PreK. The PAL-PreK was developed as representative sample of tasks found in other measures of emergency literacy skills. The subtests of the PALS-PreK include: Name Writing, Alphabet Knowledge (Upper-Case Alphabet Recognition, Lower-Case Alphabet Recognition, and Letter Sounds), Beginning Sound Awareness, Print and Word Awareness, Rhyme Awareness, and Nursery Rhyme Awareness.

Reliability and validity were assessed during a pilot of the PALS-PreK that included that a diverse sample of school programs and ethnicities (Invernizzi, Meier, & Swank, 2004). Considering the PALS-PreK as a whole, internal consistency estimates using Guttman split-half reliability and Cronbach's alpha level were in the acceptable range for all subtests. Guttman split-half statistics ranged from .71- .94. Alpha levels ranged from .75-.93. Inter-rater reliability ($r = .99$ for all tasks) was also acceptable. As measure of construct validity, factor analysis for the pilot sample yielded one factor with an eigenvalue of 2.9 verifying that the PALS-PreK measures a single factor, emergent reading skills. The PALS-PreK was compared to three established emergent literacy tests to determine concurrent validity. The correlation between the Test of Awareness of Language Systems (TALS, 1987) and the PALS-PreK was moderate-low ($r = .41$, $p < .01$). There was a moderate-high correlation between the Child Observation Record (COR, 1992) ($r = .71$, $p < .01$) and the PALS-PreK. Finally the Test of Early Reading Ability (TERA-3, 2001) showed a moderate-high correlation with the PALS-PreK ($r =$

.67, $p < .01$). Overall, The PALS-PreK is judged to offer a measure of a wide variety of emergent literacy skills needed for school success. Pilot data indicated sound psychometric properties. The focus of this study is how EF is necessary to benefit from learning activities. The Uppercase Alphabet Recognition, Rhyme Awareness, and Name Writing subtests were chosen to represent emergent literacy skills because they represent products of early learning.

Battelle Developmental Inventory, 2nd Edition. (BDI-2; Newborg, 2005). To measure the general development variable, the BDI-2 receptive language subdomain and gross motor subdomain were used. Optimally, the cognitive domain of the BDI-2 would be used, but that domain of the test was not administered. General development, as measured by the receptive language and gross motor subdomains, provided an acceptable substitute. The BDI-2 is a standardized individually administered battery of early developmental skills appropriate for children from birth through 7-years-old. The full BDI-2 battery addresses 5 domains: adaptive, personal-social, communication, motor, and cognitive. The motor domain includes gross motor, fine motor, and perceptual subdomains. The receptive language subdomain includes 40 items of increasing difficulty to assess the child's ability to respond to different sounds and words as well as gestures and other nonverbal cues. In this study, the gross motor subdomain of the motor domain and the receptive language subdomain of the communication domain were administered to provide a measure of general development. Following the guidelines suggested by Ackerman and Cianciolo (2000), the motor and receptive language subdomains were converted to z scores and then added to create the general development score.

Considering the entire BDI-2, internal reliability was measured using the split-half reliability method corrected with the Spearman Brown Formula. The average reliability coefficient for the motor domain was .92 (gross motor = .91, fine motor = .85, and perceptual = .86). The average reliability coefficient for the receptive language subdomain was .90. Generally tests are considered minimally reliable if subdomain and screening scores are above .80 and domain or total scores equal .90 or higher (Newborg, 2005). Test-retest reliability was measured in a sample of 126 4-year-olds. The test-retest correlation for the motor domain was .92 and for the receptive language subdomain was 0.83. The BDI-2 shows evidence of convergent validity through the correlation of the BDI-2 with other measures of a similar construct. For the purpose of this study, only the correlations for the motor domain and communication domain are reported. The first measure used for comparison was the Bayley Scales of Infant Development, Second Edition (BSID-II, 1993). Thirty children from birth through 3-years-old were administered both the BDI-2 and the BSID-II. The correlation between the BDI-2 motor index and the BSID-II of .64 indicates a strong relationship. The correlation between the BDI-2 communication domain and the BSID-II mental index was high at .75. The BDI-2 also shared a high level of agreement with the Denver Developmental Screening Test II with the percentage of agreement ranging from 83% to 90%. Convergent validity for the communication domain of the BDI-2 was supported when compared to the Preschool Language Scale, Fourth Edition (PLS-4; Zimmerman, Steiner, & Pond, 2002). The correlation between the receptive domain of the BDI-2 and the auditory comprehension section of the PLS-4 was relatively high (.63) as well as the correlation between the total language score and the communication domain (.73). Also of interest, the correlation

between the Wechsler Preschool and Primary Scale of Intelligence- Third Edition

(WPPSI-III, Wechsler, 2002), an individually administered measure of intelligence and

the BDI-2. In a sample of 60 children ages 4 through 7, the correlation between the

Communication domain of the BDI-2 and the WPPSI-III Full Scale IQ was .68 and

between the cognitive domain of the BDI-2 and WPPSI-III was .75. As expected the

motor domain of the BDI-2 was not highly correlated with the WPSSI-II Verbal IQ (.39),

although the correlation between the motor domain and the WPSSI-III Performance IQ

was higher (.50) possibly reflecting the motor component of some of the Performance IQ

tasks (Newborg, 2005).

Test of Early Math Ability-Third Edition (TEMA-3; Ginsburg & Baroody;

2003). The mathematic skills variable in this study was measured by use of the TEMA-3

raw score. The TEMA-3 is a norm-reference, individually administered test that includes

and provides a standard score for ages 3 years 0 months through 8 years and 11 months.

The TEMA-3 provides a raw score, a standard score (M=100, SD 15), a percentile rank,

and both age and grade equivalents, but its authors recommend caution with the standard

scores when testing 3-year-olds due to the limited range of scores. To allow for more

variability in scores for 3-year-olds, the raw scores were used for this study. The TEMA-

3 test items range from verbal counting and number identification to multiplication facts

and division. The test items involve the use of a picture book, a student worksheet, and

several types of manipulatives, such as tokens and blocks.

The TEMA-3, considered as a whole, shows strong internal reliability as

measured by Cronbach's coefficient alphas that ranged for 0.92-0.96 by age. Test-retest

reliability ranged from 0.82 for Form A to 0.93 for Form B. Item discrimination indexes

provided one measure of content validity. The median-item discrimination index on the

TEMA-3 ranged from 0.45 for 5-year-olds on Form A to 0.68 for 3-year-olds on Form B,

which appear to be acceptable (acceptable discrimination index values can be as low as

0.2, with scores around 0.35 being more typically judged as acceptable; Anastasi &

Urbina, 1997). Criterion validity was determined by comparing the TEMA-3 to other

measures of early mathematics ability. There was a moderate to strong correlation

between the TEMA-3 and other measures of early mathematics ability. For example, the

correlation between Basic Concepts of the KeyMath-R and the TEMA-3 was 0.54 and for

the Young Children's Achievement Test was 0.91.

Dimensional Change Card Sort (DCCS; Diamond, Carlson, & Beck, 2005;

Frye, Zelazo, & Palfai, 1995; Zelazo 2006). The EF variable in this study was measured

by the raw score (0-24) on the modified version of DCCS (referred to here as DCCS-

Study Version). The administration and rationale for the score created via this version are

outlined below.

The DCCS-Study Version combines elements from each of the three versions of

the DCCS and includes a separated level comprising easy items similar to that used by

Diamond, Carlson, and Beck (2005), as well as an integrated level and a mixed levels that

were described previously. The separated level will decrease the probability of a flooring

effect and allow for differentiation of EF skills among three-year-olds. The integrated and

mixed levels are similar to those found in the Toolbox version.

As recommended in the original DCCS, both the separated and integrated levels

consisted of 6 pre-switch trials and 6 post-switch trials. The mixed level has 12 total

trials. Children 36-47 months old began with the separated level, while children older

than 47 months began with the integrated level and moved back to the separated level if

they do not pass the integrated (see Table 1). A score of 5 or more out of 6 post-switch

trials is considered to be passing. Similar to the scoring procedure reported by Beck,

Schaefer, Pang, and Carlson (2011), scoring included the number of cards correctly

sorted in the post-switch trials of the separated and integrated levels as well as all 12

trials of the mixed level for a total possible score of 24. For those in the 54-66 months

age range, if the basal was established at the integrated level, then the child received full

credit for those levels prior to the basal.

Table 1

DCCS-Study Version Administration Guidelines and Scoring

Age	Starting point	Separated	Integrated	Mixed	Total Possible Score
36-47 months	Separated	**6 Pre-Switch 6 Post-Switch***	**6 Pre-Switch 6 Post-Switch***	**12 Trials***	**0-24**
		If Post-Switch score is 5 or higher, continue to Integrated Level	If Post-Switch score is 5 or higher, continue to Mixed Level.		
48-71 months	Integrated	**6 Pre-Switch 6 Post-Switch***	**6 Pre-Switch 6 Post-Switch***	**12 Trials***	**0-24**
		Administered only if child scored 4 or lower on the Post-Switch Integrated Level	Post-Switch score 5 or higher, continue to Mixed Level.		If Basal established at Integrated Level, award 6 points for Separated Level

* Indicates score on these items are included in the total score.

Primary Caregiver Questionnaire and Primary Caregiver Interview (PCQ,

PCI). Demographic information in this study included age, gender, race/ethnicity,

primary language, socio-economic status, and medical diagnosis of developmental delay,

or autism spectrum disorder. In the current study, the PCQ and PCI provided

demographic information. The PCQ was sent to all participants to be filled out before the

interview date. The questionnaire included 60 questions including basic information

about the family, languages spoken in the home, family life (e.g., time spent reading,

watching TV, playing), safety concerns, caregiver's emotional/ psychological state,

discipline, social support, nutrition/access to food, neighborhood and community,

employment, and prenatal care. The PCI is an in-depth, structured interview with the

primary caregiver that occurred on the day of the assessment. All questions were read to

the caregiver. The PCI includes 10 sections: pre-interview, respondent and child

demographics, child development, child health, health services use, insurance, welfare

and other public assistance, support services, child care, father/spouse/partner/parent

figure information, and closing/tracking. The answers to the PCQ and PCI were used to

gather demographic information about the participants as well as determine socio-

economic status (as measured by guardian education level and ratio of income to

poverty), primary language spoken in the home, and diagnoses of developmental delay

and/or autism spectrum disorder.

Procedure

This study began after approval by the University of Arizona Institutional Review

Board. Permission to access the dataset for analysis was then be granted by the First

Things First Grant research committee. The data were de-identified before provided to

the primary researcher. Once the dataset was obtained, the researcher screened the dataset

to ensure all variables of interest met the following inclusion criteria: a child between the

of ages 3-5 years without a diagnosis of developmental delay or autism spectrum disorder who completed the PCQ, PCI, DCCS, TEMA, PALS, and BDI-2 in English.

Data Analyses

This section discusses the study's statistical analysis of data, including variables associated with each hypothesis and data analyzed. An overview of the hypotheses and proposed data analyses is provided in Table 2. Data analysis was conducted using the SPSS version 22 statistical package. The data from the PCQ and PCI were used to report the combined age, gender, primary language, and socioeconomic status of the participants. Socioeconomic status was determined by guardian education and the ratio of income to poverty (reported gross income divided by poverty threshold as measured by the Census Bureau). Those with a reported diagnosis of autism and/ or developmental delay were excluded from the data analysis. Next, descriptive statistics were calculated prior to hypothesis testing on the following participant characteristics: age, gender, primary language, and socioeconomic status. Scatterplots for the predictor variables were examined to confirm assumptions needed for inferential statistics. As described above, raw scores on the DCCS, PALS, TEMA, and BDI-2 were used in the statistical analysis. Differences in age were controlled for during the statistical analysis. As described in the description of the BDI-2, the general development index will be calculated using a composite scored derived from the sum of the z scores obtained from the gross-motor and receptive language subdomains of the BDI-2.

Hypothesis one. A partial correlation was used to calculate the relationship between EF and early academic skills (early reading, writing, and math skills) when controlling for age. The first correlation explored the relationship between EF and early

reading and writing skills when controlling for age; it used the total score on the DCCS and the raw scores from the Uppercase Alphabet Recognition, Rhyme Awareness, and Name Writing subtests of the PALS-PreK. The second partial correlation explored the relationship between EF and emergent math skills; it used the total scores on the DCCS and the TEMA-3 raw score when controlling for age.

Hypothesis two. Hypothesis two predicted that EF would contribute a significant portion of variance after accounting for age, socioeconomic status, and general development in predicting early academic skills. A multiple regression with an ordered set of predictors was used to determine the contribution of EF in predicting early math skills, as measured by the total raw score on the TEMA-3. Similarly, a multiple regression with an ordered set of predictors was used to determine the contribution of EF in predicting early reading and writing skills, as measured by the Alphabet Recognition, Rhyme Awareness, and Name Writing subtests of the PALS-PreK.

Hypothesis three. Hypothesis three predicted that the contribution EF in predicting early academic skills would differ across the age span between 3-year-olds and five-year-olds (after accounting the general development). Specifically, multiple regressions with age, general development, and EF as predictors were conducted for both age groups.

Table 2

Hypotheses and Statistical Analyses

Hypothesis	EF	General Development	Age	Emergent Literacy	Emergent Math	Statistical Analysis
1	PV			OV	OV	Partial Correlation controlling for age and SES
2	PV	PV		OV	OV	Multiple regression with ordered set of predictors controlling for age and SES
3	PV	PV	PV	OV	OV	Multiple regression controlling for age. Data set for 3-year-olds and 5-year-olds compared.

Note. PV=Predictor Variable, OV=Outcome Variable

CHAPTER 4

RESULTS

Descriptive Statistics

The sample used for analysis consisted of a total of 969 participants ranging in age from 36 months to 71 months. Age of the participant was determined by the individual's age at the time of the assessment session. In the final sample, 291 children were 3-years-old (36-47 months) 409 children were 4-years-old (48-59 months) and 269 children were 5-years-old (60-71 months). From the total sample, 54.2% were female and 45.8% were male. With regard to socio-economic status, 480 participants (49.4%) met the criteria for free or reduced lunch. Three hundred and ten participants (32%) identified as Hispanic and 659 (68%) identified as Non-Hispanic. Table 3 provides more details about the demographic characteristic of the participants.

Table 3

Demographic Characteristics: Frequencies and Percentages (n=969)

Characteristic	# of Participants	%
Gender		
Female	525	54.2
Male	444	45.8
Age		
3 years	291	30.0
4 years	409	42.2
5 years	269	27.8
Race		
Hispanic	310	32.0
Non-Hispanic	659	68.0
Primarily Language		
English	933	96.3
Spanish	36	3.7
Guardian Education		
8th Grade or Less	13	1.3
9-12 grade no diploma	43	4.4
GED	22	2.3
HS Graduate	98	10.1
Vocation or trade school	39	4.0
Some College	250	25.8
Associate's Degree	83	8.6
Bachelor's Degree	235	24.3
Master's Degree	148	15.3
PhD/Professional Degree	38	3.9
Free or Reduced Lunch		
Eligible	480	49.5
Not Eligible	489	50.5

Initial analyses also concerned central tendency, dispersion of the predictor and outcome variable scores, and the intercorrelations among the variables (see Tables 4, 5, and 6). Table 4 provides a summary of the means, standard deviations, and range of scores achieved for the sample population. Table 5 breaks down the data by age band (3-year-olds, 4-year-olds, and 5-year-olds) to aid in interpretation of hypothesis 3. Finally, the intercorrelations between variables is explored in Table 6.

Table 4

Descriptive Statistics for all Variables (n=963)

Variable	Minimum Score	Maximum Score	Mean	Standard Deviation
Age in Months	36	71	52.73	8.87
Guardian Education	1	10	6.63	2.10
Poverty Ratio	0.14	9.67	2.47	1.98
Receptive Language	27	78	55.59	9.27
Gross Motor	56	90	79.49	6.47
General Development Index	-6.06	3.67	.01	1.80
DCCS	0	24	12.9	8.83
TEMA Math	0	40	11.97	8.10
Name Writing	0	7	4.29	2.63
Rhyme Awareness	0	10	5.46	2.92
Alphabet Recognition	0	26	14.23	9.93

Note. Receptive Language and Gross Motor scales reported separately and then combined in the General Development Index. All scales are raw scores other than the General Ability Index and Poverty Ratio. Possible range of scores: Age (36-71 months), Guardian Education (1-10), Receptive Language (0-80), Gross Motor (0-90), DCCS (Dimensional Change Card Sort; 0-24), TEMA (Test of Early Math Ability; 0-40), Name Writing (0-7), Rhyme Awareness (0-10), Alphabet Recognition (0-26).

Table 5

Descriptive Statistics by Age

Variable	Range	*M*	*SD*	Range	*M*	*SD*	Range	*M*	*SD*
	3-year-olds			4-year-olds			5-year-olds		
Age in Months	36 - 47	41.53	3.39	48 - 59	53.79	3.35	60 - 71	63.26	2.45
Guardian Education	2 - 10	6.92	1.90	1 - 10	6.58	2.11	1 - 10	6.38	2.19
Poverty Ratio	.17 – 8.77	2.52	1.98	.18 – 8.48	2.49	1.97	.15 – 9.67	2.39	.94
Receptive Language	27 - 65	47.42	8.63	30 - 75	57.22	6.98	44 - 78	61.98	6.18
Gross Motor	56 - 88	72.3	6.15	64 – 90	81.27	4.27	71 - 90	83.88	3.40
General Development	-6.06 -1.75	-1.89	1.62	-3.42 -3.56	.45	1.15	-1.58 -3.67	1.37	.94
DCCS	0 - 24	6.10	7.40	0 – 24	14.22	8.08	0 - 24	18.35	6.30
TEMA Math	0 - 21	5.08	4.27	0 – 38	12.48	6.43	1 - 40	18.67	7.60
Name Writing	0 - 7	1.85	2.01	0 – 7	4.84	2.29	0 - 7	6.09	1.55
Rhyme Awareness	0 - 10	3.75	2.30	0 – 10	5.66	2.82	1 - 10	7.03	2.70
Alphabet Recognition	0-26	8.71	9.28	0 – 26	14.76	9.63	0 - 26	19.43	7.84

Note. Table includes the range of scores, mean, and standard deviation at each age level. Receptive Language and Gross Motor scales reported separately and then combined in the General Development Index. All scales are raw scores other than the General Ability Index and Poverty Ratio. Possible range of scores: Age (36-71 months), Guardian Education (1-10), Receptive Language (0-80), Gross Motor (0-90), DCCS (0-24), TEMA (0-40), Name Writing (0-7), Rhyme Awareness (0-10), Alphabet Recognition (0-26).

Table 6

Correlation Matrix Among Measures of Executive Function and Early Academic Skills

(n=963)

Measure	1	2	3	4	5	6	7	8	9	10
1. Age in months	-									
2. Guardian Education	-.10**	-								
3. Poverty Ratio	-.04	.51**	-							
4. Receptive Language	.64**	.16**	.16**	-						
5. Gross Motor	.70**	-.16	.06	.64**	-					
6. DCCS	.59**	.11**	.13**	.62**	.48**	-				
7. TEMA Early Math	.67**	.18**	.21**	.72**	.59**	.65**	-			
8. Name Writing	.67**	.05	.08*	.61**	.57**	.56**	.67**	-		
9. Rhyme Awareness	.46**	.21**	.18**	.59**	.41**	.48**	.61**	.46**	-	
10. Alphabet Recognition	.44**	.25**	.23**	.53**	.38**	.52**	.68**	.57**	.48**	-

Results of the DCCS by Age

The resulting scores on the DCCS mirror those found in previous studies (Diamond, Carlson, & Beck; 2005, Diamond & Kirkham; 2005, Zelazo; 2006) as shown in Figure 5. As you can see, the majority of 3-year-olds (60.5%) failed the separated level compared to 16.5% of 4-year-olds and only 3% of 5-year-olds. In contrast, 75.5% of 5-year-olds were able to pass all levels of the DCCS.
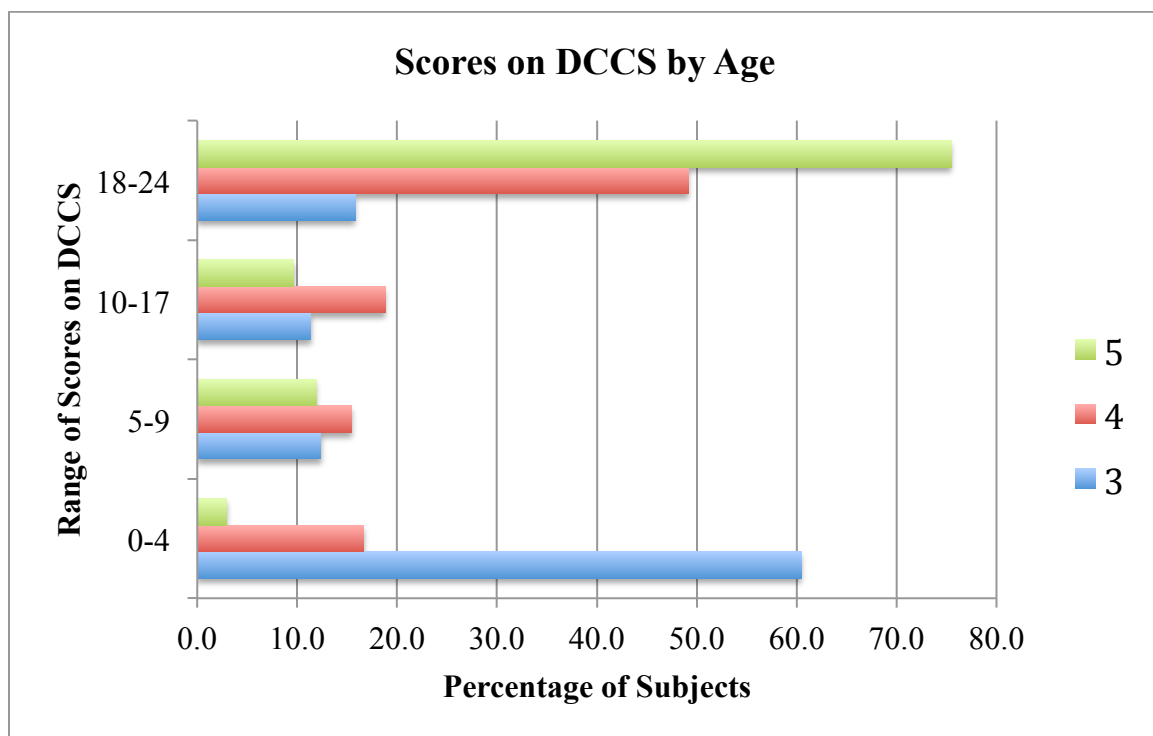

Figure 5. Percentage of subjects grouped by age range who passed each level of the Dimensional Change Card Sort (DCCS). Range of scores: 0-4 failed the separated level, 5-9 passed the separated level, 10-17 passed the integrated level, and 18-24 passed the mixed level.

Results Concerning Research Hypotheses

Hypothesis 1: Relationship between EF and early academic skills. Turning to the hypotheses in the study, hypothesis one concerned the relationship between the EF and early academic skills (after controlling for age). Preliminary analyses were performed to ensure no violation of assumptions of normality, linearity and homoscedasticity. A review of the preliminary analysis revealed that not all of the variables were normally distributed. Specifically, the predictor variable of EF and the outcome variable of name writing were negatively skewed. Consequently, a non-parametric test, Spearman's rho, was used instead of Pearson's r correlation to address the violation of normality. In order to utilize Spearman's rho, the data were transformed to be rank ordered. Spearman Rank Order Correlations were computed among the variables with the results presented in the top half of Table 7. All correlations were statistically significant and were greater than or equal to .45. In general, EF was moderately to strongly correlated with early academic skills, with higher performance on the EF measure associated with higher scores on tests of early academic skills.

Because it was noted that age in months was significantly associated with the DCCS (raw scores) and all the measures of early academic skills (raw scores), a partial correlation using the rank ordered data was conducted to examine the relationship between EF (as measured by the DCCS) and early academic achievement (as measured by the TEMA for early math skills and the PALS Uppercase Alphabet Recognition, Name Writing, and Rhyme Awareness subtests for early reading and writing skills; see Table 7). As expected, after controlling for age the partial correlations were lower than the Spearman Rank Order (non-partial) Correlations. However, there remained a strong, positive partial correlation between EF and early math skills, controlling for age, $r = .50$,

$n = 969$, $p < .01$. Early literacy skills showed a weak to moderate correlation with EF after controlling for age. Specifically, EF was moderately correlated with Rhyme Awareness, a measure of early reading skills, after controlling for age ($r = .31$, $n = 969$, $p < .01$). There was also a moderate, positive correlation between the Alphabet Recognition subtest, another measure of emergent literacy skills, and EF ($r = .38$, $n = 969$, $p < .01$). Finally, there was a weak but significant correlation between Name Writing, a measure of early writing skills, and EF ($r = .28$, $n = 969$, $p < .01$). For all outcome measures, EF was positively correlated with early academic skills after controlling for age. The strongest correlation was found between EF and early math skills, while the weakest correlation was between EF and name writing.

Table 7

Bivariate and Partial Correlations Among Measures of Executive Function and Early

Academic Skills (n=969)

Measure	1	2	3	4	5
			Spearman's rho		
1. DCCS	_				
2. TEMA Early Math	.69*	_			
3. Alphabet Recognition	.54*	.74*	_		
4. Name Writing	.55*	.72*	.61*	_	
5. Rhyme Awareness	.49*	.58*	.50*	.47*	_
6. Age	.58*	.69*	.47*	.65*	.45*

Measure	1	2	3	4	5
			Partial correlations controlling for age		
1. DCCS	_				
2. Early Math	.50*	_			
3. Alphabet Recognition	.38*	.65*	_		
4. Name Writing	.28*	.49*	.48*	-	
5. Rhyme Awareness	.31*	.41*	.36*	.45*	_

*$p < .001$ (1-tailed). All variables are rank ordered.

Hypothesis 2: EF and early academic skills after accounting for general

development. The second hypothesis concerns the contribution of EF in predicting early academic skills after controlling for age, socioeconomic status, and general development. Before conducting inferential statistical analyses, the data were first examined regarding statistical assumptions. To accomplish this, analysis was performed using IBM SPSS REGRESSION and EXPLORE. The data set met the assumptions of linearity, multicollinearity and homoscedasticity. In addition, the residuals were normally distributed indicating normality of distribution of errors. Exploration of frequency histograms indicated that the DCCS was negatively skewed. Transformation of data was explored to reduce skewness of the EF variable, but the reflect and square root, reflect and logarithm, and reflect and inverse transformations did not significantly change the shape of the distribution. The EF variable was not transformed because in a large sample such as this (*n*=969) a variable of statistically significant skewness often does not deviate enough from normality to make a substantial difference in analysis (Tabachnick & Fidell, 2013). With the use of p < .001 criterion for Mahalanobis distance, 6 outliers among the cases were identified and excluded from analysis (*n*= 963). In order to facilitate understanding, results for hypothesis 2 will be broken down into the subsections based on the skills measured: math and literacy (reading and writing skills).

EF and early math skills. To assess the ability of EF to predict early math skills (TEMA), hierarchical multiple regressions were used after controlling for the influence of age, socioeconomic status (guardian's education level and ratio of income to poverty), and general development (receptive language and gross motor skills), with results summarized in Table 8. The total variance explained by the model as a whole was 64%,

$F(5, 957) = 340.35$, $p < .001$. Regarding the key question of EF's contribution to predicting early math skills, EF indeed explained an additional 4% of the variance, after controlling for age, socioeconomic status, and general development, $\Delta R^2 = .04$, F change $(1, 957) = 109.85$, $p < .001$. Regarding the contribution of EF in the final model, although all predictors made statistically significant contributions to predicting early math skills, the highest standardized coefficient value was associated with general development ($\beta= .33$, p $< .001$) with the standardized coefficients for age ($\beta = .29$, $p < .001$) and EF ($\beta = .27$, $p < .001$) falling slightly lower.

Table 8

Summary of Hierarchical Regression Analysis for Variables Predicting Early Math Skills in Young Children (n=963)

Variable	R^2	ΔR^2	β
Step 1 (control variables)	.53*	.53*	
Age			.69*
Guardian education			.17*
Poverty ratio			.15*
Step 2 (general development)	.60*	.07*	
Age			.38*
Guardian education			.12*
Poverty ratio			.11*
General development			.42*
Step 3 (EF)	.64*	.04*	
Age			.29*
Guardian education			.10*
Poverty ratio			.10*
General development			.33*
EF			.27*

*p < .001

EF and early literacy skills. Because early literacy skills were measured with three different outcome variables (Name Writing, Alphabet Recognition, and Rhyme

Awareness), the results of each outcome variable will be discussed separately below. Please refer to Table 9 for a summary of results.

Name writing. To determine the contribution of EF in predicting early writing ability, a hierarchical multiple regression analysis was conducted with age, socioeconomic status (maternal education and income to poverty ratio), general development (receptive language and gross motor skill composite), and EF as factors. Of primary interest, EF accounted for an additional 2% of the variance and the model as a whole accounted for 52% of the variance $F(5, 957) = 209.60$, $p < .001$. When holding all other variables constant, one standard deviation change in EF would result in .18 change in name writing scores ($\beta = .18$, $p < .001$).

Alphabet recognition. Similarly, to assess the ability of EF to predict early literacy skills (Uppercase Alphabet Recognition) a hierarchical multiple regression was performed (after controlling for the influence of age, socioeconomic status, and general development). The total variance explained by the model as a whole was 38%, $F(5, 957) = 114.98$, $p < .001$. Critically, EF explained an additional 5% of the total variance in predicting alphabet recognition ($\Delta R^2 = .05$, F change $(1, 957) = 70.26$, $p < .001$). Additionally, the standardized coefficient indicates that as EF increases by one unit, alphabet recognition scores would increase by .28 ($\beta = .28$, $p < .001$).

Rhyme awareness. As for the final outcome measure of early literacy, the ability of EF to predict early literacy skills (Rhyme Awareness) was measured using a hierarchical multiple regression after controlling for the influence of age, socioeconomic status, and general development. After the addition of EF, the total variance explained by the model as a whole was 36%, $F(5, 957) = 110.17$, $p < .001$. The model that included

EF explained an additional 2% of the variance in the early literacy skill of rhyme awareness, $\Delta R^2 = .02$, F change $(1, 957) = 29.79$, $p < .001$. The standardized beta coefficient allowed for a comparison of the relative importance of predictors as all variables are converted to the same scale. Of all the predictors, general development was the strongest ($\beta = .32$), p<.001) with EF as the second strongest ($\beta = .18$, $p < .001$).

   Secondary analysis. A secondary analysis was run to determine the contribution of EF without controlling for SES. This is so because the second research question concerns the contribution of EF beyond the contribution of general development (a theoretically important and practically meaningful question). Including SES in EF's ability to predict early academic skills is inconsistent with these theoretical and practical considerations. To determine the additional contribution of EF without the added effect of SES, hierarchical regressions with age and general development added at step 1 and EF added at step 2 were completed for each academic outcome measure. The additional variance (ΔR^2) contributed by EF increased slightly when SES was removed from the model for all academic measures except name writing. When removing SES as a factor, EF explained an additional 5% of the variance (beyond general development) in early math skills, 3% for rhyme awareness, 6% for alphabet recognition, and 2% for name writing.

Table 9

Summary of Hierarchical Regression Analysis for Variables Predicting Early Literacy Skills in Young Children (n=963)

Variable	Alphabet Recognition			Rhyme Awareness			Name Writing		
	R^2	ΔR^2	B	R^2	ΔR^2	β	R^2	ΔR^2	β
Step 1 (control variables)	.29***	.29***		.28***	.28***		.46***	.46***	
Age			.46***			.48***			.68***
Guardian education			.23***			.21***			.09*
Poverty ratio			.13***			.10**			.06*
Step 2 (general development)	.33***	.04***		.35***	.06***		.50***	.04***	
Age			.24***			.19***			.44***
Guardian education			.20***			.16***			.05*
Poverty ratio			.10***			.06*			.03
Gen development			.30***			.39***			.31***
Step 3 (EF)	.38***	.05***		.37***	.02***		.52***	.02***	
Age			.15***			.13**			.38***
Guardian education			.17***			.15***			.04
Poverty ratio			.09**			.05			.02
Gen Development			.20***			.32***			.25***
EF			.28***			.18***			.18***

*p < .05, ** p < .01, *** p <.001.

Hypothesis 3: EF and academic skill by age. The third and final purpose of the study was to explore if the contribution of general development and EF remains constant between 3 and 5 years of age. To address this hypothesis, standard multiple regressions with EF, general development (as measured by the receptive language and gross motor composite), and age as predictor variables were conducted for the sample of 3-year-olds and the sample of 5-year-olds. Early math skills (TEMA) and early literacy skills (Name Writing, Uppercase Alphabet, and Rhyme Awareness) were the outcome variables measured. Separate multiple regressions was run for each outcome variable (i.e., Name Writing, Uppercase Alphabet, and Rhyme Awareness) resulting in a total of 4 standard regressions for 3-year-olds and 4 standard regressions for 5-year-olds. Scores for each outcome variable are reported for both the 3-year-old group and 5-year-old group in order to facilitate comparisons between the groups. Table 10 presents a summary of scores.

For the 3-year-old data set, preliminary analyses were conducted to ensure no violation of the assumptions of normality, linearity, multicollinearity and homoscedasticity. The 3-year-old data set met all assumptions. For the 5-year-old data set, transformation of data was explored to reduce the negative skewness of the EF and name writing variables, but the reflect and square root transformation caused both variables to be positively skewed. After consulting the distribution of the residuals and finding them to be normally distributed, it was decided to not transform the EF and name writing variables. Because the sample met the assumptions of linearity, multicollinearity and homoscedasticity and because of the robust sample size, it was determined that the important assumptions were met and the multiple regressions could be run despite the two skewed distributions. It has been argued that normality of distribution is a weak

assumption that can addressed by the use of a large sample size ($n > 200$) and by careful interpretation of the results (Tabachnick & Fidell, 2013; Gelman & Hill, 2007). In addition, the use of a p < .001 criterion for Mahalanobis distance one outlier among the cases was found and removed from the analysis, $n = 268$.

Early math skills. The greatest difference in the contribution of EF to early academic skills was seen in the area of math. EF was a stronger predictor of early math skills (as measured by the squared semi partial correlation) at age 3 ($\beta = .42$, $sr^2 = .14$, $p < .001$) than at age 5 ($\beta = .20$, $sr^2 = .03$, $p < .001$). Interestingly, at age 3 general development was a slightly weaker predictor ($\beta = .36$, $sr^2 = .10$, $p < .001$) compared to EF. In contrast, for the sample of 5-year-olds, general development was the stronger predictor of math skills ($\beta = .51$, $sr^2 = .22$, $p < .001$) compared to EF. Overall, the data indicated that the unique contribution of EF in predicting early math skills does vary between the 3-year-old and 5-year-old age group with EF a stronger predictor for the 3-year-old age group.

Early literacy skills (reading and writing). In the area of early literacy skills, the contribution of EF (after controlling for general development and age) remained relatively stable across the age groups and outcome measures. For the outcome measure of alphabet recognition, EF remain consistent between age groups ($\beta = .33$, $sr^2 = .09$, $p < .001$, $\beta = .26$, $sr^2 = .07$; respectively). Also of interest, the EF standardized coefficients were greater than those for general development. Similar to EF, for general development standardized coefficients remained consistent between the two age groups (3-year-olds: $\beta = .21$; 5-year-olds: $\beta = .23$). As for name writing, the contribution of EF was not significant but remained stable between the group of 3-year-olds ($\beta = .09$, $sr^2 = .01$, $p = $

.04) and 5-year-olds: $\beta = .09$, $sr^2 = .02$, $p = .16$). Of secondary concern, for the academic

outcome of name writing, general development was a stronger predictor than EF at both

age groups. Regarding the final outcome variable for this hypothesis, rhyme awareness,

the contribution of EF remained relatively stable and was a weaker predictor than general

development in both cases (3-year-olds: $\beta = .19$, $sr^2 = .03$, $p = .002$; 5-year-olds: $\beta = .22$,

$sr^2 = .04$, $p < .001$). In summary, the contribution of EF remained relatively stable

between the ages of 3 and 5 for early reading and writing skills.

Table 10

Summary of Multiple Regression Analysis for General Development and EF in Predicting

Early Academic Skills in 3-year-olds (n=291) and in 5-year-olds (n=268)

Variable			3 Year Olds					5 Year Olds		
	B	SE B	β	part	R^2	B	SE B	β	part	R^2
Math										
TEMA					.45*					.39*
Age	.11	.06	.09	.08		.13	.15	.04	.04	
General development	.96	.13	.36*	.31		4.15	.43	.51*	.47	
Executive function	.23	.03	.39*	.36		.24	.06	.20*	.18	
Literacy										
Alphabet Recognition					.20*					.18*
Age	-.05	.16	-.02	-.02		.15	.18	.05	.05	
General Development	1.18	.35	.21*	.18		1.86	.51	.23*	.20	
Executive function	.41	.07	.33*	.30		.35	.08	.28*	.26	
Literacy										
Name Writing					.20*					.13*
Age	.15	.03	.25*	.23		.06	.04	.09	.09	
General Development	.30	.08	.24*	.21		.48	.10	.30*	.26	
Executive function	.03	.02	.09	.08		.02	.02	.10	.09	
Literacy										
Rhyme Awareness					.11*					.29*
Age	.00	.04	.00	.00		.06	.06	.06	.06	
General development	.33	.09	.23*	.20		1.19	.16	.41*	.37	
Executive function	.05	.02	.17	.15		.09	.02	.22*	.20	

* p < .001

CHAPTER 5
DISCUSSION

This study investigated the relationship between EF and early academic skills in young children. The specific area of interest was the unique contribution of EF to the acquisition of early skills such as letter recognition, name writing and basic math skills. This chapter presents the study's results in the context of the current literature as they relate to the hypotheses. Limitations of the present study and future implications are also discussed.

The first purpose of the present study was to establish if EF is indeed associated with early academic skills. The EF-academic link is documented in elementary students, but it is not clear if this association also exists among younger students at the very beginning of academic skill acquisition. It is hypothesized that students require EF in order to follow the rules of the classroom, attend to lessons, complete tasks, and effectively transition from one task to another throughout the day. It makes sense that well developed EF would contribute to early school success as well. For example, EF is needed to self-monitor during letter recognition tasks and to change strategies or correct actions given input from a caregiver or teacher. Indeed, that was what was found in the current study. A well-standardized measure of EF (DCCS) and valid and reliable measures of early academic skills were associated even as early as three-years-old. A moderate to strong link was found between EF and academic skills with the strongest correlation between EF and early math skills. Generally, these findings appeared to substantiate previous research that suggests EF is associated with early math performance and early reading performance to a lesser extent. Consistent with previous research, there was a moderate to strong relationship between EF and math and a slightly weaker but

significant relationship between EF and literacy (Blair & Razza, 2007; Clark, Pritchard & Woodward, 2010; Duncan et al., 2007; Pagani, Fitzpatrick, Archambault, & Janosz, 2010; Welsh, Nix, Blair, Bierman, & Nelson, 2010). A moderate to strong relationship between EF and academic skills among 3-to 5-years olds supports the idea that EF is an important ability needed for early school success. Further discussion of the relationship between EF and early academic skills follows.

It is logical to ask if any EF-early academic association might merely reflect youngsters' differences in general cognitive development. The logic is that both EF and early academic skills are associated with general development and that any EF-academic association might simply reflect a joint association with general development. Although IQ was not measured, a proxy for general development was used. Using this indicator of general development it was possible to determine the contribution of both general development and EF to early academic skills using hierarchical multiple regression. As predicted after controlling for all factors including general development, EF continued to contribute a significant amount of variance in early academic skills. The specific results related to early math and reading skills are discussed separately below.

EF and Early Math Skills

As expected, EF contributed a significant amount of variance in predicting early math skills after controlling for general development. The present findings are consistent with the results of previous studies that examined EF and math skills among school-age children, namely Bull and Scerif (2001) and Gathercole and Pickering (2000). Similarly, the minimal research available in younger children (3- to 5-year olds) reported a significant and strong relationship between EF and early math skills after accounting for

general intellectual abilities such as language ability (Blair & Razza, 2007) or both verbal comprehension and processing speed (Clark, Sheffield, Wiebe & Espy, 2013). No other EF studies of preschoolers were found that included a measure of general development or IQ. Accordingly, these findings indicate EF should be considered an important component in early math skill acquisition above and beyond general development. For school age children, it is easy to see the relation of EF and math ability as proficiency in math requires many problem-solving components such as the ability to represent information in working memory and shift between the various elements of the problem presented. In contrast, some of the beginning math problems presented at younger ages such as simple addition or subtraction facts appear to depend more on long-term memory and fluency. However, it appears that that for young children early math skills, such as number identification, one to one correspondence, and concepts such as shape recognition, do make explicit demands on EF skills.

A unique aspect of this study was that the EF measure included the specific ability of cognitive shifting. The most commonly used measures of EF in the literature focus on working memory, attention, or response inhibition. With the use of the DCCS, the current study was able to explore the predictive contribution of flexible cognitive shifting, an EF aspect missing from the current available research for young children. When looking specifically at cognitive shifting, several studies have indicated a link between EF and math achievement at the school age level (Bull & Sceriff, 2001; McLean & Hitch, 1999), but few studies have included a measure of cognitive shifting in younger children. The available studies of preschool age children that included cognitive shifting as a separate variable found no relationship with early math skills (Espy et al., 2004;

Monette, Bigras, & Guay, 2011). Conversely, the current study found cognitive shifting, as measured by the DCCS, to contribute a significant portion of variance to early math skills.

There are several reasons why the present study may have found a relationship whereas previous studies did not. First, the current study included a larger sample size (*n*=963) compared to the much smaller sample sizes in previous studies (*n*=85-96). The probability of finding a difference if one exists (i.e., power) is much greater with a large sample size. A second reason may have been that the measure of cognitive shifting used in the previous studies was too difficult for young children. This may have caused a flooring effect in those studies, whereas the DCCS is developmentally sensitive to changes within the age range of 3-5 years old (Carlson, 2003). A third and final reason involving the difference between the cognitive shifting tasks is worth mentioning. Espy and colleagues (2004) used two tasks to measure cognitive shifting and both incorporated a reward for correct response per trial. The presence of tangible rewards is one factor that distinguishes "hot" EF and from the "cool" EF measured in the current study (Hongwanishkul, Happaney, Lee, & Zelazo, 2005). Previous research has shown that "hot" EF tasks activate a different part of the brain than "cool" EF and that there are individual differences between hot and cool EF (Happaney, Zelazo, & Stuss, 2004; Beck, Schafer, & Carlson, 2011). The difference in the nature of the tasks (hot versus cool) may account for the difference in results between the two studies. In summary, given the developmental sensitivity of the test used in this study and the additional power provided by its large sample size, this study provides evidence that EF, and cognitive shifting in particular, is likely a significant factor in predicting early math skills.

EF and Early Reading Skills.

Current findings suggest that EF plays a significant role in acquiring early reading skills. It was predicted that, as with early math skills, EF would continue to explain a significant amount variance to the outcome measures of alphabet recognition and rhyme awareness after accounting for any shared variance between general development and EF. Confirming this hypothesis, EF was a significant predictor of both measures of early reading skills. This association may occur because success in early literacy skills requires understanding of a rule-governed reading system including applying the correct set of letter sounds based on graphemes. To use this system effectively, children must keep several phonological rules in working memory while simultaneously applying the appropriate rule depending on the letter or group of letters currently present. It seems plausible that young children with less developed EF may have difficulty selecting and applying the appropriate rule due to lack of cognitive flexibility (Crosbie, Holm, & Dodd, 2009). At a young age, reading skills are not yet automatic and require more effortful use EF. Eventually, as development unfolds, there is a degree of automaticity to these skills is achieved. As this developmental progress occurs, EF may play a smaller role in basic reading skills in later years (Blair & Razza, 2007.)

Of particular interest, EF's contribution to rhyme awareness was smaller than that of alphabet recognition. This finding supports Blair and Razza's (2007) findings of no significant relationship between EF and measures of phonemic awareness. The reason for this difference in effect size may be that rhyme awareness is an aspect of general development rather than a product of academic instruction. It is hypothesized that while letter recognition is a product of early learning experiences (a skill directly taught in the

classroom or by a parent), successful performance on rhyme awareness reflects more of an innate ability and amount of exposure to literature (exposure to print in the home, exposure to nursery rhymes, songs, etc.). Perhaps this difference in the nature of the task may account for the smaller effect size reported for rhyme awareness. Furthermore, this finding provides support that EF is important for products of early learning such as letter recognition and less important when measuring early characteristics that may mirror general cognitive maturity.

EF and Early Writing Skills

Among existing research, writing skills are not typically measured when examining EF and early academic skills. Interestingly, EF contributed a significant amount of variance to early writing skills (as measured by the Name Writing subtest of the PALS) in the current study. This finding is similar to the significant contribution of a card sorting task similar to the DCCS and a reading/writing composite in Monette, Bigras, and Guay's (2011) study. No other studies of EF and early academic skills in preschoolers were found that provided a separate writing measure. However, the predictive relationship of EF to writing skills is consistent with the literature in older children (Altemeier, Jones, Abbott, & Berninger, 2006; Hooper, Swartz, Wakely, de Kruif, & Montgomery, 2002). These studies have found that children with higher scores on measures of EF such as initiation, inhibition, and cognitive shifting, scored higher on writing tasks. Specifically, Hooper et al. found a significant predictive relationship in 4th and 5th graders between EF and writing outcomes after accounting for reading ability. Typical writing tasks presented to young children (such as the name writing task used in the current study) are different from those of a typical 4th or 5th grader, but nonetheless

the tasks require EF skills. Learning to write is an executive process that uses sound-to-symbol relationships as well as motor abilities to form the correct letters, in the correct spaces, and also in the correct order. A child must shift between these various cognitive schemas in order to successfully write a word or name. In addition, the child must plan what is to be written and then self-monitor to determine if what was planned appears on the paper. Given the small amount of unique variance contributed by EF in the present study, other variables, particularly motor skills, may be as important as EF, if not more so, at this developmental period.

Changes to the Contribution of EF Over Time

Given the rapid changes in development between the early preschool years, the final purpose of the study was to determine if EF is an equally important predictor of early academic skills for three-year-olds and five-year-olds. Comparing the two age groups, the results indicate changes in the contribution of EF in the area of math with minimal changes for letter recognition, name writing, and rhyme awareness. In the area of math, EF was a stronger predictor at age 3 than at age 5. When learning math skills, it appears that EF in an important ability for children of all ages, but the results of the current study emphasize the importance of EF in the initial acquisition of early math skills around age 3 (Bull & Lee, 2014).

A secondary concern is how the contribution of EF compares to that of general development. In the area of math, general development was a weaker predictor than EF for 3-year-olds. The reverse was true for the sample of 5-year-olds, with general development being the stronger predictor. For the outcome measure of letter recognition, EF was the stronger predictor in both age groups. This is consistent with the earlier

conclusion that EF is required during the learning phase of skills such as letter identification, before skills become relatively automatic. For both rhyme awareness and name writing, the contribution of EF as a predictor remained relatively constant between the age groups, with general development as the stronger predictor. This is consistent with the previous discussion that perhaps rhyme awareness is a product of the general development process more than a measure of material formally taught in school. For name writing, this result in consistent with the idea that name writing relies heavily on motor skills (a part of the general development index).

Limitations

Whereas the present study presents some significant findings, several factors limit these results and must be addressed. The first limitation is regarding the amount of missing data among participants. Due to missing data on the gross motor index of the BDI-2 there was a lack of available general development information for many of the participants. The gross motor index, comprised of 45 items, was used to create the general development index. Those participants with missing data were excluded from the final analysis. A majority of the participants with missing data on the gross motor index were missing the 2 questions (out of 45) pertaining to stairs. In Arizona, a large number of households do not have stairs and young children may not have as much experience using stairs when compared to children in other geographic locations. The data from those participants missing the questions related to stairs may have differed in some way that was not detected through the preliminary analysis, weakening the internal validity of the study.

A second limitation resulted from the exclusionary criteria of the study. Given

the nature of the hypotheses, participants who completed the Spanish version of the tasks were excluded in order to reduce unintentional contributing factors such as the use of non-standardized versions of the test and factors related to learning a second language. Excluding students who completed the Spanish version of the tasks decreased the diversity of the sample and subsequently may have decreased the generalizability of the results.

Future Implications

This study confirms results found in many past research studies in the area of EF and early academic skills. Furthermore, the present study supplements available research by extending the research to a younger age group, utilizing a measure of cognitive shifting that is sensitive to developmental change, including a measure of early writing skills, and increasing sample size. The current study also highlights possible areas for further research.

The conclusion that EF is a significant predictor of early academic skill achievement has important implications for researchers, psychologists, and educators. The 3-5 years age span is a time of rapid development of EF skills, and this change was apparent in rapid transformation of scores on the DCCS from age 3 to age 5. It would be a great asset for psychologists and clinicians to have access to a quick assessment tool of EF that would highlight the need for further assessment. At the present time, the DCCS does not possess the needed attributes in a screener tool due to the lack of norm-referenced data. In addition, there remain some concerns about the utility of EF measures at a young age. Some doubt remains about the ability of the DCCS and other similar measures to differentiate EF from other phenomenon such as IQ or general development.

At age 3, these skills are not yet differentiated. As researchers such as Hughes and Ensor (2007) as well as Wiebe, Espy, and Charak (2008) have shown, at a young age EF loads as one factor that shares substantial variance with factors such as IQ. In other words, when measuring EF at age 3, there is great overlap with IQ making it difficult to tease apart the contribution of these 2 components. To be of use clinically, the EF measure would need more research in the area of convergent and divergent validity, particularly at the 3-year-old age range. Also norm referencing and standard scores would make the test more useful for use by psychologists in a clinical or school setting.

Based on the results of the current study, when a child experiences early school difficulties, a closer look at the nature of the difficulty may help to determine if an EF deficit exists and ultimately help the school team to develop appropriate interventions. For instance, recent research by Espinet, Anderson, and Zelazo (2013) indicates that young children respond readily to top-down teaching strategies such as reflection training. In addition, research indicates that parental and teacher support through scaffolding assists in the development of EF in children as young as 3-years-old (Hammond, Müller, Carpendale, Bibok, & Liebermann-Finestone (2012). If the child is experiencing difficulty with early learning products such as recognizing letters or numbers, then deficits with EF may be contributing to that difficulty. Educators can then use scaffolding techniques and specific accommodations to address differences in EF skills. For psychologists, particularly those working in the school setting, measures of EF can be used as part of the child find or kindergarten transition process. Psychologists can inform IEP teams of accommodations in the general curriculum that may be beneficial

for a student with a deficit in EF. Providing these accommodations at an early stage in the child's education might promote later academic success.

This study explored the role of EF in the development of early writing skills that was not addressed in the current body of literature. Knowledge of EF and early writing skills could be enhanced by extending the EF battery to include a variety of abilities in order to determine which executive processes are utilized most in early writing development. Another important addition would be to include a measure of fine motor skills to determine the unique ability of EF to predict writing skills above and beyond motor skills. Given the nature of writing tasks, it is expected that fine motor skills would be an essential factor in predicting early writing ability.

Another area for further exploration would be the role of bilingualism as a mediating factor in EF predicting early academic skills. There is some evidence that being fluently bilingual may actually enhance EF (Bialystok, 1999, 2011; Mueller Gathercole, Thomas, Jones, Guasch, Young, & Hughes, 2010). It seems logical that EF abilities would be strong in bilingual children as many of these abilities are required when speaking two languages. For example, cognitive flexibility is needed when shifting from one language to another and self-monitoring is needed when determining when to speak each language. However, all research studies about EF and early academic skills to date have included exclusively English speakers. Within the current dataset, the large amount of students who completed the tasks in Spanish could provide information about the mediating role of bilingualism in EF predicting early academic skills.

Keeping in mind that the dataset in the current study was cross-sectional, there is also a need for longitudinal data in order to better explore the developmental changes that

occur in the contribution of EF to early academic skills. In order to examine developmental shifts in abilities, longitudinal studies would be able to explore the changes within the individual child by measuring the same subset of skills over time to provide important insight into the developmental process of EF as well as academic outcomes.

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