Executive Function Development and Early Mathematics: Examination of Dual Language Learners

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EXECUTIVE FUNCTION DEVELOPMENT AND EARLY MATHEMATICS:
EXAMINATION OF DUAL LANGUAGE LEARNERS

A Dissertation
Presented to
the Morgridge College of Education
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Hattie A. Harvey
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Abstract

This study examined the convergent validity between a third-party rating scale of executive function (EF) and a task-performance measurement of EF; examined the effects of age, gender, and dual language experience on preschool children’s EF skills (inhibition, working memory (WM), and shifting) and on early mathematical skills; and investigated the contributions of inhibition, WM, and shifting to early mathematical skills. Ninety-two children attending Head Start were assessed. Correlation analyses revealed a number of relationships between the EF rating scale and the EF task-performance measure. A multivariate analysis of variance revealed a main effect of age on all EF measures and the math assessment and a significant difference between language groups on the measures of inhibition and shifting. Finally, hierarchical regression analyses revealed that WM and inhibition made unique contributions to children’s early mathematical skills, and vocabulary scores made more contribution to early mathematical skills than either inhibition or WM. These findings extend previous research by (a) highlighting the issues involved with the assessment of EF in young children; (b) further supporting findings of preschool age-related changes in EF; (c) demonstrating EF differences with a DLL population; and (d) highlighting the importance of WM, inhibition, and language to mathematical learning, demonstrating the effects in early childhood. Implications of these findings for EF assessment in young children and prekindergarten curricula are discussed.
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Chapter One: Introduction

School readiness and young children’s preparedness to succeed at the academic and behavioral demands of school have been a focus of developmental and educational research for many decades. Recently, legislation such as the No Child Left Behind Act has resulted in a heightened interest in better delineation and understanding of the diverse skills that contribute to children’s academic success and failure. Of particular concern are the delays in school readiness often experienced by children growing up in poverty and by those who are English language learners. There are substantial achievement gaps both between middle-income children and low-income children and between monolingual English speaking and English language learners (ELLs) at school entry that widen over time and contribute to serious disparities in learning difficulties, educational attainment, and long-term employment potential (Ballantyne, Sanderman, & McLaughlin, 2008; Carlo et al., 2009; Ryan, Fauth, & Brooks-Gunn, 2006; Zehr, 2009). According to a compilation of reports from forty-one state educational agencies, only 18.7 percent of students classified as Limited English Proficiency (LEP) met the state norm for English (Kindler, 2002). Flagship programs, such as Head Start, and rapidly emerging programs, such as public school prekindergarten, are designed to reduce these disparities by enhancing school readiness.

One of the largest demographic shifts over the last ten years is the sharp increase in the number of students in public school who speak English as their second language,
and these children are more likely to come from low-income communities (National Clearinghouse for English Language Acquisition, NCELA, 2007). For the purposes of this study, the term dual language learner (DLL) will be used, as suggested by the NCELA (Ballantyne et al., 2008), to refer to young children who are acquiring both the language of their family as well as the language of the larger community. A simple estimate of the numbers or proportions of DLLs in the early childhood population was not found. However, according to a report from the NCELA (Ballantyne et al., 2008), the numbers of children who are DLLs as well as their proportion of the population are rising. For 3- and 4-year-olds, the best population estimate comes from Head Start data. In 2006, nearly one in three Head Start or Early Head Start children came from families where a language other than English is spoken (Ballantyne et al., 2008).

Thus significant questions remain concerning optimal prekindergarten school practices for economically disadvantaged children (Love, Tarullo, Raikes, & Chazan-Cohen, 2006) and for children who are DLLs (Han & Briglall, 2009). On the one hand, evidence that emergent literacy and numeracy skills are strong predictors of later reading and math achievement (e.g., Duncan et al., 2007) suggests that prekindergarten programs for children from low-income homes might reduce school readiness disparities most effectively by focusing more time on direct instruction designed to build skills in these specific domains (Lonigan, Burgess, & Anthony, 2000). On the other hand, developmental research suggests that the preschool years represent a critical period for the development of the mental processes that support effective, goal-oriented approaches to learning, particularly working memory and attention control, both considered to be components of executive function. These mental processes are often delayed in children
growing up in poverty (Noble, Norma, & Farah, 2005), and appear to play a central role in predicting school adjustment and academic attainment (Blair & Razza, 2007; Holmes & Adams, 2006; McClelland et al., 2007). Prior research conducted with elementary school students has suggested that working memory and attention control (also referred to as inhibition) play a key role in supporting emergent literacy and mathematical computation and problem-solving skills (Mazzocco & Kover, 2007; Passolunghi, Vercelloni, & Schadee, 2006; Swanson & Sachse-Lee, 2001). Educational research is beginning to examine these skills during early childhood when they are undergoing rapid growth.

However, it is important to recognize the limitations of current research within the overlapping areas of executive function, early childhood, dual language learners, and school achievement. Within the literature, two different approaches exist on how these overlapping areas are researched. Some researchers approach this topic utilizing a process-oriented focus, focusing on domain-specific growth in cognition/brain development. This stems from a developmental, cognitive, and/or neuropsychology background. Other researchers approach this topic from a content-oriented focus, focusing on domain-specific growth in an academic content area. This stems from an educational background. The present study aims to integrate these two approaches by examining the relations between executive function and mathematics achievement within an early childhood population and providing practical implications for practice.

Executive Function

Findings from recent studies in the domain of developmental psychology have advanced our knowledge about early executive function as a critical factor of child
development. Executive functions are critically important in the overall neuropsychological functioning of the developing child and play a fundamental role in a child’s cognitive, behavioral, and social-emotional development. Recent studies have advanced our knowledge about the different cognitive constructs that fall under the broad category of executive function, and have also identified developmental trajectories unique to each executive function skill (Bull, Espy, & Wiebe, 2008; Bull & Scerif, 2001; Carroll, 2007; Mazzocco & Kover, 2007; St Clair-Thompson & Gathercole, 2006). A number of definitions for executive function have been offered, which delineate specific components (e.g., Barkley, 1997; Blair, Zelazo, & Greenberg, 2005; Carlson, Mandell, & Williams, 2004; Carroll, 2007; Espy, 2004; Fang & Qiwei, 2005). Despite the range of skills included in specific definitions, most would agree with the definition offered by Isquith, Crawford, Espy, and Gioia (2005) that the general term “executive function” is “an umbrella construct defined as the control and self-regulatory functions that organize and direct all cognitive activity, emotional response, and overt behavior” (p. 209). For purposes of clarification, the terminology “executive function” refers to a broad construct, whereas “executive functions” or “executive function skills” refer to the components, and “executive functioning” refers to an active process of the construct. For the remainder of this paper, the acronym EF references the construct, the acronym EFs references the specific components, and reference to the active process will remain ‘executive functioning’ with no acronym.

Decades of research have focused on understanding EF in school-age children and adults. More recently, there has been an increase in focus on understanding the structure, organization, and development of EF in young children under five years of age, in part
due to the substantial evidence that EF relates to achievement in school-aged children (e.g., Gathercole & Pickering, 2000; Gathercole, Pickering, Knight, & Stegman, 2004; Halperin & Bedard, 2009), and also due to its integral function with cognition and social behavior (Anderson, 2002; Bull et al., 2008; Carlson et al., 2004; Carroll, 2007; Espy, Bull, & Senn, 2004a; Gnys & Willis, 1991; Isquith et al., 2005; St Clair-Thompson & Gathercole, 2006). Specific components of EF that have been studied with the preschool population include inhibitory control (e.g., Blair, 2003; Diamond, Kirkham, & Amso, 2002; Espy & Bull, 2005), working memory (e.g., Blair, 2003; Hughes, 2005; Senn, Espy, & Kaufman, 2004; Zelazo, Muller, Frye, & Marcovitch, 2003), and cognitive flexibility and shifting (e.g., Diamond, Carlson, & Beck, 2005; Senn et al., 2004; Smidts, Jacobs, & Anderson, 2004; Zelazo et al., 2003). It is suggested that these three EF components (inhibition, working memory, and cognitive flexibility or shifting) can be clearly delineated in preschool-aged children as three separate factors under the construct of EF (Espy, 2004; Friedman & Miyake, 2004; Marcovitch & Zelazo, 2009; Miyake, 2000; Senn et al., 2004; Zelazo et al., 2003).

Conceptually, these skills enable children to organize their thinking and behavior with increasing flexibility, decrease their reactive responding to contextual cues and contingencies, and engage in self-regulated and rule-governed behavior (Barkley, 2001; Blair & Diamond, 2008; Gathercole et al., 2008). By promoting children’s capacity to inhibit impulsive responses and to choose alternative responses, these cognitive control capacities enable children to regulate the emotions and/or behaviors that motivate and inform their experiences (Kochanska, Murray, & Harlan, 2000). Developmental researchers have postulated that EF skills, particularly working memory and attentional
control, facilitate school readiness and early learning by supporting behavioral self-regulatory capacities and social competence (Hughes & Ensor, 2007) and by fostering children’s capacities to engage more effectively with teachers and peers in classroom learning activities (Gathercole et al., 2008).

**Limitations to Current EF Research**

There are three major limitations in current research and include: (a) the lack of EF measurement tools for use with young children; (b) the lack of research on EF development in DLLs; and (c) the limitation of research approaches which result in recommendations for classroom practice.

First, due to the recent focus of research in this area, the availability of standardized assessment tools to measure EF in young children is limited. One challenge to measuring EF in young children is the variable nature of behavior and limitations in motor and verbal proficiency in this age range (Espy, Kaufmann, Glisky, & McDiarmid, 2001). Additionally, wide-ranging conceptualizations of EF have complicated measurement of EF in young children (Senn et al., 2004). Several assessment tools have been developed to enable more effective measurement of EF in young children. The majority of such tools are adaptations of measures originally developed for adults, which take into account young children’s limitations in motor, language, and sustained attention skills.

The literature outlines two assessment approaches in young children. One approach is the use of a rating scale, such as the *Behavior Rating Inventory of Executive Function-Preschool* (BRIEF-P; Gioia, Espy, & Isquith, 2003). An alternative approach to assessing EF in young children is the use of performance-based tasks. Performance-based
tasks are a direct measure of children’s ability to produce solutions to a problem; whereas third-party rating scales are an indirect measure of children’s abilities. Most studies of EF have used a variety of separate performance-based tasks, depending on what aspects of EF are being measured. To date, there is no consistent performance-based methodology for measuring the three identified components (inhibition, shifting, and working memory) in a single measure. Thus, one of the main goals of the current research project is to examine the utility of a new performance-based EF measure for preschool children called the NIH Toolbox (Gershon & Zelazo, 2009), which measures all three EF components.

The second limitation of the literature is the lack of research investigating EF development in DLLs. As previously mentioned, this is a growing population within the United States, and thus it is necessary to understand the cognitive development of DLLs in order to help inform educational practices for use with this population. Executive functions in bilingual populations have been examined in multiple studies (e.g., Bialystock, 1999, 2001; Bialystock & Martin, 2004). However, the bilingual population in these studies was defined as either exposure to two languages since birth or proficiency in two languages. The NCELA makes a clear distinction between children who are bilingual and children who are DLLs, with the latter as young children who are co-developing two languages (Ballantyne et al., 2008). Interestingly, there is some evidence to suggest that specific components of EF, namely inhibitory control, attention, and flexibility, develop more rapidly in children with extensive bilingual experiences (Bialystock, 2001; Bialystock & Martin, 2004). It is important to note that the term DLL is relatively new, and that in the literature, the terms DLL, bilingual, and ELL are not consistently differentiated. For the purposes of this study, investigating the development
of EFs in DLLs may help to inform classroom practices and strategies used for teaching and working with this population, as defined by the NCELA.

The third limitation of the literature is that the majority of the research on the development of EF stems from neuroscience and cognitive psychology approaches, which may limit the direct applicability and utility of the results to educational settings. The present study aims to connect the results with clear implications for classroom practice, which may ultimately advance young children’s school readiness. Bull et al. (2008) suggest that supporting the development of EF skills can provide children with an immediate advantage in an early learning environment by aiding the acquisition of early mathematics and reading skills that are maintained throughout elementary education. Children with poor executive functioning may make errors in a range of learning activities that are due to difficulty remembering and carrying out instructions, inhibiting irrelevant information and staying focused on task, and planning and monitoring progress on a task. Identifying patterns in EF development from an educational approach may provide a link to recommendations for classroom instruction and individualized intervention that can target and support areas of EF development.

**Executive Function and Mathematics**

In addition to understanding the development of EF in young children, findings from recent studies have also demonstrated associations between EF skills and skills from other cognitive domains, including mathematics (Bull & Scerif, 2001; Mazzocco & Kover, 2007). A relationship between EF skills and math ability has been identified with school-aged and adult populations (Jarvis & Gathercole, 2003; Holmes & Adams, 2006; Kytitala, Aunio, Lehto, Van Luit, & Hautamaki, 2003; Maybery & Do, 2003; St Clair-
Recently, a number of studies have examined the relationship between EF skills and math ability in young children (e.g., Bull et al., 2008; Espy, Bull, Weibe, & Sheffield, 2009; Espy et al., 2004b; Mazzocco & Kover, 2007). A predictive relationship has been identified between young children’s EF skills and their later math performance (Bull et al., 2008; Mazzocco & Kover, 2007). This will be expanded upon in chapter 2 of the literature review.

However, the majority of studies that have explored the relationship between EF and mathematics have used only a single math domain (usually arithmetic) to correlate with specific EFs (e.g., Bull, Espy, & Weibe, 2008). A number of other early mathematical domains have been identified as critical foundations in young children’s knowledge of mathematics including early numeracy, geometry/spatial reasoning and measurement, and patterning and logical relations. Such concepts have been identified to reflect the earliest developmental concepts that preschool children can acquire (Clements & Sarama, 2007; Klein & Starkey, 2004). More work is needed to assess the relationships that occur between EF skills and specific early math domains in young children.

Although research in this area is limited (e.g., Bull et al., 2008; Haplerin & Berdard, 2009), the outcomes from this research study add new insights about the relationship between EF and early math knowledge which can help to inform classroom instructional recommendations.

Limited research addresses the differences between monolingual English speaking children and DLLs in regards to early mathematical knowledge and EF. As previously mentioned, some researchers have explored EF development in young children who are bilingual (e.g., Bialystock, 2001; Bialystock & Martin, 2004), which is clearly
differentiated from children who are DLL (NCELA, 2007). Because children from non-
English speaking backgrounds represent the fastest growing population in school 
enrollment (NCELA, 2007), identifying the cognitive processes of children who are DLLs has implications for practice and curriculum development within early childhood settings that serve children who are DLL.

**Early Mathematics**

Finally, it is also important to recognize the need for more research in the area of early mathematics development, and specifically with children from low SES families. In several recent, comprehensive Head Start reports (U.S. Department of Health and Human Services, 2003; 2005), participating children have not made significant gains in critical early mathematical areas. Data from Head Start Family and Child Experiences Survey (FACES; U.S. Department of Health and Human Services, 2003) show that in the year 2000, children entered Head Start on average at the 21st percentile in early mathematics, as defined as early numeracy, and left on average at the 23rd percentile. In the Head Start Impact Study (U.S. Department of Health and Human Services; 2005), no significant gains in early mathematics were found for 3- and 4-year-old children attending 383 randomly selected participating Head Start programs spread over 23 states. Such findings clearly indicate the need for a closer look at what factors might impact and further support mathematics development in early childhood Head Start populations. Important advances in metacognitive process research has led some to suggest that variation in early mathematical skills might be closely related to the development of EF skills and metacognitive processes (Carr & Jessup, 1995; Desoete, Roeyers, & Buysse, 2001; Senn et al., 2004).
Both the National Association of Education for Young Children (NAEYC) and the National Council of Teaching Mathematics (NCTM) joint position statement (NAEYC & NCTM, 2002) and the Head Start Performance Standards (Administration of Children and Families, 2006) identify concepts related to supporting mathematics and cognitive development of children. More specifically, the NAEYC and NCTM joint position statement (2002) notes that effective mathematics teaching requires understanding of what students know and need to learn, and then challenging and supporting them in order for them to acquire new skills. Similarly, the Head Start Performance Standards state that “…agencies must provide for the development of each child’s cognitive and language skills…by supporting emerging literacy and numeracy development through materials and activities according to the developmental level of each child” (Administration for Children and Families, 2006, 1304.21(4)(a)(i-iv)). Both of these statements emphasize the need to support numeracy development through a greater understanding of early cognitive skills, including EFs, which may impact a child’s mathematics skill development. A need exists for further research on the relationship between the development of mathematical components of early numeracy, arithmetic, geometry and spatial reasoning, and patterning and logical relations and the development of EF components of including inhibition, shifting, and working memory.

**Summary of the Introduction**

To summarize, the present study has three primary components. First, this research study examines the concurrent validity and utility of a new performance-based EF assessment tool for use with preschool populations and dual language learners. The use of both the BRIEF-P rating scale and the NIH Toolbox performance-based measure
in the same study will allow for an examination of convergent validity between an indirect and a direct measure across the domains of inhibition, shifting, and working memory. Second, this research study adds to the literature on the development of EF in young children, and specifically examines differences in performance between DLLs and monolingual English speaking children. Third, the results from this project help to identify the contribution of inhibition, shifting, and working memory to early mathematical knowledge as conceptualized by four early math domains (number tasks, arithmetic tasks, space/geometry tasks, and pattern/logical relations tasks).

Although executive functions are interrelated and there is considerable overlap between the components of EF, a broad approach to each area is discussed separately within the literature review to gain a clearer understanding of the complexity of this topic. The literature review addresses the following topics: a) definitions and theoretical models of executive function; b) components of executive function, c) development of executive function in young children; d) assessment of executive function in young children; e) executive function and bilingual children; f) early mathematics development, and g) the interrelation between executive function and mathematics abilities. Based on the literature, the following are the three research questions that are addressed in this study:

1. What is the convergent validity between the performance-based EF tasks and the rating scale measure of EF for each of the three factors?

2. Are there differences in performance between ages, genders, and language groups on these executive function measures and on the four early math domains?
3. Does a performance-based measure of EF predict critical early math skills in the domains of early numeracy, arithmetic, geometry/spatial reasoning and measurement, and patterning and logical relations, when controlling for vocabulary knowledge and previous Head Start experience?
Chapter Two: Literature Review

The term “executive function” and the cognitive processes involved have been described from numerous perspectives. Over time, there has been a gradual shift in understanding EF, with early notions describing a homogenous set of processes, and not differentiating among individual components. Recent studies have advanced our knowledge about the different cognitive components that fall under the broad construct of EF and have identified developmental trajectories unique to each EF component. Although EF is a complex cognitive construct, it is clear that EFs play a critical role in learning and development. This construct is not new to the field of psychology, but has been a topic of interest for many decades.

Definitions and Theoretical Models of Executive Function

The study of executive function and the role of the frontal lobe in human behavior is extensive and dates back as early as the mid eighteenth century, when Harlow (1868) first described a patient’s changing behavior as result from a brain injury. His descriptions represent a metaphor for the role of the frontal lobe. He describes the frontal lobe as serving as an executive, responsible for making decisions, forming goals, planning, organizing, devising strategies for attaining goals, and changing and devising new strategies when initial plans fail. Although the construct of EF was first introduced by Luria in 1966, theoretical consensus about the construct has been slow to develop. The complex nature of EF along with a historical lack of consensus regarding its definition
leads to wide variation in how EF is studied and measured. Nevertheless, many of the current theories and conceptualizations share common roots based on Luria’s (1966) model of EF.

Based on the roots of Luria’s model, there have been two broad approaches to the development of executive function frameworks. The first considers EF as a unitary construct with constituent subprocesses (e.g., Baddeley, 1986; Norman & Shallice, 1986). For instance, in both Baddeley’s (1986) and Norman and Shallice’s theories (1986), a central attention system is thought to regulate various subprocesses. The second broad theoretical approach emphasizes dissociable, or componential, EF processes. Those most frequently cited in the developmental literature are cognitive shifting, working memory, and inhibition (e.g., Diamond, 2006; Hongwanishkul, Happaney, Lee, & Zelazo, 2005; Pennington, 1997; Welsh, Pennington, & Groisser, 1991; Zelazo et al., 2003). For the purposes of understanding EF within the framework of the current research study, Luria’s influential model along with various models inspired by Luria’s work will be reviewed below, with an emphasis on developmental theories.

Luria’s theory (1966) of the brain’s functional systems is at the root of his account of executive function (Welsh, 2002). Luria referred to the front lobes as “the organ of civilization” because of their association with intentionality, purposefulness, and complex decision making. Luria’s theories are based on extensive neuropsychological assessments that he completed with patients who had brain injuries. He noted that damage to the prefrontal cortical areas of the brain was associated with compromised conscious control of behavior and diminished EF skills. His patients were commonly impulsive and were
unable to organize their behavior to achieve a goal, yet they retained their preinjury knowledge base. Drawing from his clinical observations, Luria developed a model of EF that included three cognitive mechanisms: an arousal component, a sensory component and an output planning component. According to Luria (1966), the brain consists of three functional units, and it is the third unit in which EF mechanisms operate. The first functional unit is located mainly in the brain stem and is responsible for regulating and maintaining arousal of the cortex. The second functional unit is responsible for encoding, processing, and storage of information and encompasses the temporal, parietal, and occipital lobes. The third functional unit is located in the anterior region of the brain (frontal lobes) and its functions include programming, regulating, and directing behavior. Within the third unit, the prefrontal cortex is considered by Luria as a “superstructure” that regulates or controls mental activity and behavior. Many current theories that describe how information is processed and used to direct behavior to achieve a goal include some variation of these cognitive mechanisms. Three elements of EF originally identified by Luria appear consistently in more contemporary accounts of this construct.

In her early work, Lezak (1982) built upon Luria’s model by emphasizing the role of executive functions in relation to social behavior. Lezak wrote that the EFs of the frontal lobes were:

> . . . the heart of all socially useful, personally enhancing, constructive, and creative abilities . . . Impairment or loss of these functions compromises a person’s capacity to maintain an independent, constructively self-serving, and socially productive life no matter how well he can see and hear, walk and talk, and perform tests. (Lezak, 1982, p. 281)

In a comprehensive review of neuropsychological assessment procedures, Lezak (1995) states that “…executive functions are capacities that enable a person to engage
successfully in independent, purposeful, self-serving behaviors” (p. 42). She suggests that EF is a unified construct that may be conceptualized as having four components: (a) volition; (b) planning; (c) purposeful behavior; and (d) effective performance, with each involving a distinctive set of activity-related behaviors. Lezak distinguishes between cognitive abilities, which may be seen as domain specific, and executive skills, which act more globally and have impact upon all aspects of behavior. She argues that the integrity of these functions is necessary for appropriate, socially responsible behavior.

Norman and Shallice (1986) extended Luria’s idea of frontal lobe functioning and came up with their supervisory attentional system (SAS) model. According to this model, the programming, regulating, and verifying of behaviors and thoughts involve two systems: contention scheduling and supervisory attention. The first system is responsible for routine and learned behaviors or tasks that allow us to prioritize the order of these behaviors and tasks (e.g., drawing a picture while talking to a friend). This could also be conceptualized as similar to what is often referenced to as cognitive shifting. The second system is responsible for regulating non-routine and novel tasks. In particular, there are five types of situations in which routine, automatic activation of behavior would not be sufficient for optimal performance (Norman & Shallice, 1986). These included situations: (a) that involve planning or decision-making; (b) that involve error correction or troubleshooting; (c) in which responses contain novel sequences or actions; (d) where danger is anticipated; and (e) which require the overcoming of a strong habitual response or resisting temptation. This model adds to Luria’s original model by introducing the “supervisory attention” as an important aspect of executive functions. Currently, many
researchers agree that attentional control, also referenced to as inhibitory control (e.g., Espy & Bull, 2005), is a specific domain or subskill of executive function (Anderson, 2002; Barkley, 1997; Fuster, 2002; Liebermann, Giesbrecht, & Müller, 2007; Nigg, 2000; Welsh et al., 1991; Zelazo et al., 2003). Others postulate that attentional control may be a latent factor that mediates the correlation between the EF components (Garon, Bryson, & Smith, 2008).

According to Stuss and Benson’s (1986) original model, there are three systems that interact together to monitor an individual’s attention and executive functions. Two of the systems are responsible for maintaining an individual’s alertness, and the third system is involved in the executive attentional control. Stuss, Shallice, Alexander, and Picton (1995) expanded upon Norman and Shallice’s (1986) model to further our understanding of how the relationship between the schema and the supervisory attentional system (SAS) might operate. The authors identify an integrated model of EF, including a set of associated skills which allow the individual to develop goals, hold these goals in active memory, monitor performance, and control for inference in order to achieve these goals. According to Chan (2008), a strength of this model is that each executive attentional component is on a neural basis. For example, the authors linked the ability to sustain attention to the right frontal cortex and the ability to switch attention the dorsolateral prefrontal and medial frontal areas (for more detailed description on the neural basis see Stuss, 2005). This model proposed that EF is not a single construct, rather the specific executive processes are thought to be associated with distinct frontal lobe systems, and that executive processes demonstrate variable developmental profiles.
Also reflecting Luria’s influence, Fuster (1997) describes EF as the processes that temporarily organize action toward biological or cognitive goals. For example, Fuster’s (1985) original model of EF includes two temporal components along with an inference control set that suppresses behavior that is not goal directed or useful in the generation of a response to a novel problem. Fuster’s (1985, 2002) model of EF includes two references to temporal characteristics: temporally retrospective working memory and temporally prospective anticipatory set. These characteristics allow for the use of information held in memory as a guide for prospective actions. Thus, he emphasizes that temporal mediation of thought and action is a critical aspect of EF. Along with the ability to organize action across time, EF components access and organize the sensory, motor, and mnemonic contents, thus allowing for the creation and temporal structuring of new and complex goal-directed actions. Fuster’s model, along with the previous mentioned models set the stage for exploring EF from a developmental perspective.

**Developmental perspectives.**

A number of theories evolved from the need to understand the developmental emergence of executive functions. Developmental theorists have constructed theoretical frameworks of EF that delineate the components as having different developmental trajectories. Luria’s theoretical foundation for how organized goal-directed action is accomplished remains, but developmental differences are addressed through the lens of a developmental framework of EF. Three important developmental theories of executive function are reviewed.
Welsh & Pennington (1988) first described executive functions as overlapping, integrated components. They defined executive functioning from a developmental perspective as the ability to maintain problem-solving in order to attain a future goal. More recently, Pennington and Ozonoff (1996) view the components of EFs as distinct from cognitive domains such as sensation, perception, language, working memory, and long-term memory. They see it as overlapping with such domains as attention, reasoning, and problem-solving (Pennington & Ozonoff, 1996, 54). They also add inference control (similar to Fuster’s (1985) original model), inhibition, and integration across space and time as other aspects of EF. Their central view is:

Executive function is a context-specific action selection, especially in the face of strongly competing, but context-inappropriate, responses. Another central idea is maximal constraint satisfaction in action selection, which requires the integration of constraints from a variety of other domains, such as perception, memory, affect, and motivation. Hence, much complex behavior requires executive function, especially much human social behavior. (Pennington & Ozonoff, 1996, 54)

In other words, their central view of EF is that it allows a person to inhibit behavioral responses and to make appropriate choices in a specific situation, while integrating information from a variety of other cognitive processes. Further, Pennington (1997) proposes a developmental approach to EF that accounts for individual differences.

Similar to Welsh and Pennington’s (1988) original model, others have proposed models of EF based on the developmental perspective that particular skills are available to the individuals depending on their developmental stage. For example, Barkley’s (1997) model provides a sequence for the development of executive skills beginning in infancy. His model contains five essential elements: (a) behavioral inhibition; (b) working memory (nonverbal); (c) self-regulation of affect/motivation/arousal; (d) internalization
of speech (verbal working memory); and (e) reconstitution, all of which emerge at different developmental periods. The cornerstone of this model is behavioral inhibition, which according to Barkley, begins to emerge in the 5- to 12-month age range. Within Barkley’s model, he emphasizes that as development occurs, the capacity for mental representations and strategy knowledge increases, and these control processes may become more explicit. Anderson (2002) also proposed a model based on the developmental perspective similar to Barkley’s work, but extended it to include a goal setting domain. Anderson also suggested, similar to Stuss and Benson’s (1986) model, that the attentional control processes are the foundation of executing functioning, while information processing, cognitive flexibility and goal setting domains are inter-related and inter-dependent. The term *attentional control processes*, used by Stuss and Benson (1986) and Anderson (2002), and the term *behavioral inhibition*, used by Barkley (1997), are both supported in their models as being the foundation of executive functioning, and could be considered interchangeable terminology.

The cognitive complexity and control theory – revised, proposed by Zelazo and his colleagues (Zelazo & Frye, 1998; Zelazo & Muller, 2002; Zelazo et al., 2003) is used to explain the variation in children’s abilities to shift attention from one aspect of a rule to another. Complexity theories of cognition apply an information processing approach to the analysis of the structure of EF (Zelazo et al., 2003). Within the framework of complexity theories of EF, there is a hierarchal structure of children’s rule systems that depend on age-related increases in the degree to which children can reflect on rules. Recent research by Zelazo et al. (2003) demonstrated the use of complexity theories to
understand EF, but added a revision to these theories to specify more clearly the circumstances in which children will have difficulty using rules at various levels of complexity. The characteristics of complexity theory lend support to the notion that at various developmental states different relationships may exist between components of EF. Awareness of the stage-dependent nature of EF is useful for guiding interpretation of findings about the relationships between components and subskills. While Luria was mainly concerned with complex cognitive functions in adults, complexity theories promote the consideration of EF within a developmental framework.

Definitions put forth by many other researchers (e.g., Baddeley, 2002; Diamond, 2006; Espy, 2004; Miyake & Friedman, 2000; Welsh, 2002) also reflect Luria’s (1966) original model. The temporal aspects of cognition, the recruitment of basic cognitive processes, and the response to novelty are all key elements in the conceptualization of EF. However, different conceptualizations of EF remain based on varying theoretical roots in neurology, cognitive psychology, developmental psychology, neuropsychology, and educational psychology. Over the last decade, with accumulating evidence to support both unitary and componential views of EF, the literature has shifted toward the integration of these perspectives (Baddeley, 2002; Friedman & Miyake, 2004; Miyake & Friedman, 2000; Shallice, 2002). This is well represented in a review of EF development during the preschool period in which EF is thought of as a unitary construct, with partially dissociable components (Garon et al., 2008). In general, recent research has focused on using a variation of path models and factor analysis to further delineate and understand the underlying structure of EF. For example, Diamond (2006) supports a
componential view of EF development, noting that working memory, inhibition, and
cognitive flexibility (shifting) show different developmental trajectories and are unique
subcomponents in children ages 3-5 years old. For the purposes of this study, the
identified components of EF by Diamond (2006) and many other researchers will be
examined. These include cognitive flexibility/shifting, inhibition, and working memory.

**Components of Executive Function**

Typically, descriptions of executive function are characterized by considerable
overlap in the way that the components are conceptualized and operationalized. This
overlap makes it difficult to separate individual skills. Many proponents of the
componential view have used path models and confirmatory factor analysis to delineate
the components of EF (e.g., Senn et al., 2004; Gioia, et al., 2003; Hughes, 1998; Miyake
et al., 2000; Pennington, 1997) and agree that performance on different EF tasks cluster
into distinct functional domains (Espy, McDiarmid, & Glisky, 1999; Friedman &

However, there is variation in the models that exist within the literature and they
are found to differ for adults versus young children. For example, Miyake and Friedman
(2000) used confirmatory factor analysis to investigate whether frequently used EF tasks
loaded onto different factors (i.e., were distinguishable) and loaded on a common EF
factor (i.e., were related). A model with three factors – inhibition, shifting, and updating –
was found to be tenable with an adult population. Miyake and Friedman concluded that
both the communality and specificity of the EF components should be recognized. They
also suggest, as did Barkley (1997) and others, that inhibition might be the key factor
given that all EFs involve inhibitory processes. Also using confirmatory factor analysis, both Gioia et al., (2003) and Espy & Cwik (2004) identified inhibitory control as a separate factor in preschool children. These are just a few examples of the literature demonstrating that inhibition is a delineated factor of EF among all ages (Espy & Kaufmann, 2002; Friedman & Miyake, 2004; Miyake, 2000). There is now accumulated evidence using factor analysis that three distinct components of EF can be delineated in the preschool-age populations: cognitive flexibility/shifting, inhibition, and working memory (e.g., Bull et al., 2008; Espy & Cwik, 2004; Espy, 2004; Gioia et al., 2003).

In addition to distinguishing EF components using factor analysis, some researchers have suggested that EFs can be divided into “cold” and “hot” components (Zelazo & Muller, 2002; Hongwanishkul, Happaney, Lee, & Zelazo, 2005) or functions involving less or more emotional response than others. Zelazo and Muller (2002) distinguished between two aspects of EFs: the relatively hot affective aspects and the more purely cognitive cool aspects, each associated with a different part of the prefrontal cortex. The cold components include verbal reasoning, problem-solving, planning, sequencing, the ability to sustain attention, resistance to interference, utilization of feedback, working memory, multitasking, cognitive flexibility, and the ability to deal with novelty. The hot components include the regulation of one’s own social behavior and the decision-making involving emotional and personal interpretation (Zelazo & Muller, 2002). There continues to be a debate within the literature as to whether the components of EF can be differentiated into hot/cold categories (e.g., Carlson, 2005).
Based on the developmental literature, the present research study focuses on three specific executive functions that have been identified to be separate factors underlying the construct of EF in young children: (a) cognitive flexibility/shifting; (b) inhibition; and (c) working memory. A broad conceptual approach to each component will allow for the discussion of the overlapping skills that exist within each of these components.

**Cognitive flexibility/shifting.**

Some researchers differentiate between cognitive flexibility and cognitive shifting (e.g., Hughes, 2005) while others do not (e.g., Liebermann, et al., 2007; Qu & Zelazo, 2007; Zelazo, et al., 2003). Many researchers have used the term interchangeably or have referenced one term to represent the underlying meaning of both. There is a clear agreement on the overlap of skills. Both cognitive flexibility and shifting require the ability to shift between response sets, learn from mistakes, devise alternative strategies, divide attention, and process multiple sources of information concurrently (Anderson, 2002; Garon et al., 2008; Isquith et al., 2004). Similarly, shifting, as described by Baddeley (1986), is the ability to shift attention or to shift between strategies or response sets. Shifting can be characterized by the disengagement of an irrelevant task set or strategy and the subsequent activation of a more appropriate one. In many developmental models (e.g., Anderson, 2002; Barkley, 1997), working memory is also an element of cognitive flexibility and shifting. Inflexible individuals are generally considered rigid and ritualistic, struggling when new activities or procedures are changed and failing to adapt to new demands. Cognitive flexibility and shifting are essential for problem-solving in
novel situations, when environmental demands change or when an old response set is no longer appropriate.

In summary, shifting, as described in the literature, refers to an individual’s ability to move freely from one situation, activity, or aspect of a problem to another, as the circumstances demand. Key aspects of shifting include the ability to make transitions, problem-solve flexibly, switch or alternate attention, and change focus from one mindset or topic to another. Mild deficits in the ability to shift can compromise the efficiency of problem solving, whereas more severe difficulties are reflected in perseverative behaviors (Gioia et al., 2003).

**Inhibition.**

Inhibition is the ability to suppress dominant, automatic, or prepotent responses (Liebermann et al., 2007). Barkely (2003) describes “prepotent responses” as “those for which immediate reinforcement is available for their performance or for which there is a strong history of reinforcement in this context” (p. 83). In the developmental and pediatric literatures, the term inhibition has been used to describe both the suppression of a prepotent (and typically somatic, motor response) and the control of attention. In other words, there is a distinction between cognitive engagement/disengagement among internally represented rules or responses sets that are previously active versus those currently active (Niggs, 2000). In suppression tasks, or response inhibition, the child must suppress somatic motor responses—for example, remaining still while the examiner tries to distract the child. In attention control tasks, or inference control, the child must inhibit
an internally represented rule or response that had been previously active and now must be disengaged and controlled.

Friedman and Miyake (2004) found evidence for this distinction in adults using structural equation modeling, where normative adult task performance was characterized by inhibiting a prepotent response versus controlling attention to resist interference from a previously active rule or response set (also known as inference control). Similarly, Espy and Bull (2005) also found evidence of this distinction, but in young children as it related to their short-term memory processes. They found that performance across inhibitory process demands (attention control vs. response suppression) differed in children with high and low memory span lengths. In Barkley’s (1997) model, he refers to the term behavioral inhibition, which is also viewed as consisting of two related processes: (a) the capacity to inhibit prepotent responses, either prior to or once initiated, creating a delay in the response to an event (response inhibition); and (b) the protection of this delay, the self-directed actions occurring within, and the goal-directed behaviors they create from interference by competing events and their prepotent responses (inference control).

According to Barkley (1997), inhibition sets the stage for the development of nonverbal working memory and is interrelated with working memory. Diamond (1988) suggests that inhibition and working memory are inextricably linked; for example, if an individual is not able to maintain information over time in order to inhibit incorrect responses, he or she will continue to choose the incorrect response, thus suggesting that working memory is needed to make correct responses. In contrast, some researchers have delineated inhibition and working memory as distinct components (e.g., Bull et al., 2008; Senn,
Espy & Kaufmann, 2004), and this delineation is further discussed in the development section.

In summary, two main processes are identified in the literature that conceptualize the term inhibition: (a) response inhibition, the ability to resist previous motor patterns; and (b) inference control, the ability to inhibit attention to previous mental descriptions. Inhibition is necessary for goal-directed behavior as it allows for individuals to think before they act and to decide when and if they will respond. Without inhibition, the ability to use planning, goal-directed persistence would be very difficult. For young children, inhibition is also conceptualized as the first and most basic step in self-control because it gives the child the power to respond or not respond to a person or event.

**Working memory.**

The term working memory refers to a limited capacity system responsible for simultaneous storage and manipulation of information during performance (Baddeley, 1986). According to the most widely accepted model (Baddeley, 1986; Baddeley & Hitch, 1974) working memory consists of at least three components: (a) the central executive which is without storage capacity and which is assumed to monitor and control two subsystems; (b) the phonological loop; and (c) and the visuospatial sketch pad. The phonological loop, also identified as verbal working memory (Barkley, 1997; Welsh, 2002), is considered to be responsible for temporarily storing and rehearsing auditory information. The visuospatial sketch pad, also identified as visual working memory is considered to process and store visual and spatial information. Baddeley (2002) identified the episodic buffer as a further subcomponent of working memory, responsible for
integrating information from the subcomponents of working memory and long-term memory. Working memory is clearly differentiated from short- and long-term memory, as stated by Pennington and Ozonoff (1996), “while working memory interacts with short-term memory and long-term memory they are conceptually distinguishable systems” (p. 62).

Drawing from Baddeley and Hitches’ (1976) classic structural model of working memory, Welsh’s (2002) model characterizes working memory as “as system of memory stores including a limited capacity central executive system and two slave subsystems, the phonological/articulatory loop and the visual spatial scratchpad” (p. 153). Similarly, Barkley (1997) also identified two components of working memory that he conceptualized as nonverbal and verbal working memory. Nonverbal working memory becomes the foundation for the child’s ability to make decisions and control behavior even though a person or an activity is not present. Barkley refers to the activation of past images as ‘hindsight’ or the ‘retrospective function’ of working memory. Verbal working memory is defined as the internalization of speech, which is fostered by the acquisition of language. The internalization of speech facilitates the development of rules, problem-solving strategies, self-monitoring, self-instruction, and metacognition (Barkley, 1997).

Recently, St. Claire Thompson and Gathercole (2006) distinguished between verbal and visuospatial measures of working memory in a population of 11- and 12-year-old children and found related links between these abilities and academic outcomes in the areas of reading and math. There is now substantial evidence in the literature that
supports the distinction between verbal (phonological loop) and visual (visuospatial sketch pad) working memory.

In general, working memory allows for the transient storage and processing of information (Baddeley, 1986) and is a critical cognitive component associated with EF (Welsh, 2002; Zelazo et al., 2003). Working memory involves the simultaneous manipulation and maintenance of a representation so that the representation can guide responses to problems. Dehn (2008) describes working memory as constituting the combination of moment-to-moment awareness, efforts to maintain information in short-term memory, and the effortful retrieval of archived information. Despite multiple definitions of working memory and its subcomponents, its interrelation with other EFs is clearly demonstrated (e.g., Barkley, 1997; Bull et al., 2008; Zelazo et al., 2003). Working memory is essential for carrying out multistep activities, implementing a sequence of actions, or following complex instructions. In review of the literature and for the purposes of this study, working memory is defined as the capacity to hold information in mind for the purpose of completing a task or making a response.

**Development of Executive Function in Young Children**

One of the challenges for understanding EF in children is that these skills typically develop rapidly through childhood, with the suggestion that progression is not necessarily linear, but may occur in spurts and at certain ages, particularly the 3- to 6-year-old period (Carlson, 2005; Diamond, 2001; Marcovitch & Zelazo, 2009; Rothbart & Posner, 2001). During the preschool years, there is a rapid development of executive functions, specifically those identified in the previous section being shifting, inhibition,
and working memory (Bull & Scerif, 2001; Diamond, 2006; Espy et al., 1999; Gargon et al., 2008; Hughes, 2002; Jacques & Zelazo, 2001). Because underlying skills associated with EF are conceptualized in diverse ways across studies, tasks used to assess specific components vary. Studies that trace the development of EF often differ in how the specific components are operationalized and which developmental periods are targeted. Research continues to explore the delineation as to which EF components develop at what ages and what other factors are involved.

Despite continued research efforts on the development of EF in young children, behaviors associated with EFs have been demonstrated in the literature to begin in infancy. The development of attentional control, future-oriented, intentional problem solving, and self-regulation of emotion and behavior are all considered to begin in infancy (Diamond, 1985; Haith, Hazen & Goodman, 1988) and continues into the preschool period (Rothbart & Posner, 2001; Welsh, et al., 1991). For example, early manifestations of EFs, such as goal-directed, planful problem-solving behaviors in infants, have been demonstrated with the use of object permanence and object retrieval (Diamond, 1985; Diamond, 2006). Espy and Kaufman (2002) reviewed infant studies of inhibition and working memory using the A not B and delayed response tasks and found that infants between 8 and 12 months of age were unable to resist looking in the original location despite direct observation of the reward being hidden in the alternate location. At 12 months, they were able to inhibit the prepotent response and look in the correct alternate location (Espy & Kaufmann, 2002), showing a developmental change in inhibition abilities. In toddlers, executive self-control abilities, such as maintaining an
intentional action and inhibiting behavior to attain a goal, are actively developing (Senn et al., 2004). Thus, early intentional self-control behaviors are present in infants and toddlers and contribute to goal-directed problem solving. Furthermore, the development of these skills in preschool-age children has been demonstrated in numerous studies (e.g., Carlson, 2005; Carlson & Moses, 2001; Murray & Kochanska, 2002; Welsh et al., 1991).

Some recent research has identified the three specific EF components, cognitive shifting, inhibition, and working memory, as showing developmental change in preschool children (Diamond, 2006; Garon et al., 2008; St Claire Thompson & Gathercole, 2006), each of which also account for a unique variance in a variety of achievement related outcomes (e.g., Bull & Scerif, 2001; Espy et al., 2004b; Halperin & Bedard, 2009; Mayberry & Do, 2003; Mazzocco & Kover, 2007; St. Clair-Thompson & Gathercole, 2006). For the purposes of the present research study, the development of these three specific EF components is explored in more detail. Due to the compilation of literature which often discusses inhibition and working memory simultaneously, and cognitive shifting separately, the topics are discussed in the aforementioned format.

**Development of inhibition and working memory.**

Inhibition and working memory have been identified to develop earlier, whereas the more complex processes, such as systematic problem-solving and planning, have a more protracted course (Barkley, 1995; Espy, 1997). Emergence of inhibition has been studied across infants and young children using various forms of delay response tasks and attentional measures (Espy, et al., 1999; Marcovitch & Zelazo, 1999, 2009), or a modification of elicited imitation tasks (Weihe & Bauer, 2005). Ironically, one of the
challenges in understanding the development of inhibition is the multitude of inhibition tasks or tools used to assess inhibition. Many of the tasks involve working memory in addition to response inhibition. Such tasks examine a child’s ability to use a rule to exert control over behavior. Some authors have argued for the importance of the distinction between tasks requiring both inhibition and working memory and tasks that require inhibition alone (Carlson & Moses, 2001; Diamond et al., 2002; Diamond, Carlson, & Beck, 2005). Empirical evidence supports this distinction. Factor analyses of data from inhibition tasks have consistently indicated that simple and combination inhibition tasks cluster into different factors (Carlson & Moses, 2001; Garon, et al., 2008; Murray & Kochanska, 2002). Carlson and Moses (2001) make a useful distinction between ‘delay’ tasks, which require children to delay a prepotent response, and ‘conflict’ tasks, which require children to make a novel response while inhibiting a conflicting, prepotent response. Further research suggests that conflict tasks are more strongly related to working memory capacity than are delay tasks (Carlson, Moses, & Breton, 2002).

Using path analysis to understand the organization and development of inhibition and working memory components in preschool children, Senn et al., (2004) found that the contributions of working memory and inhibition accounted for 29% of the variance in complex problem solving and suggested that these two components are central to EF processes. The authors demonstrated a distinction in the development of inhibition and working memory, identifying that inhibition was a stronger determinant of problem solving in younger children (≤ 4), whereas working memory was more important in older children (>4). The authors suggest that these findings may represent the different
maturational timetable of these abilities. Inhibitory control may develop more rapidly in younger children, with more protracted development in working memory (e.g., Espy, 1997; Welsh et al., 1991). In contrast, Zelazo et al. (2003) found evidence that for 3- and 4-year-old children, there were no differences between tasks that impose working memory demands with relatively low inhibition demands and tasks of the converse, and suggested that tasks involving primarily one demand were relatively easy for preschool children. However, tasks that imposed both working memory and inhibition were found to be more difficult.

Developmental progression of executive functions is also demonstrated in a cross-sectional study of 602 preschool children on a variety of EF tasks (Carlson, 2005). In this cross-sectional sample from 24 months to 4 years, Carlson found age differences in the length of time children are able to delay. Whereas 50% of 24-month-olds were able to suppress eating a treat for 20 seconds, 85% of 3-year-olds suppressed the urge for one minute. This ability appears to improve throughout the preschool period, with 72% of 4-year-olds being able to suppress eating a treat for 5 minutes. Overall, Carlson demonstrated that aggregate EF scores improved significantly from 3 to 5 years, even after they controlled for the relation between EF and verbal ability. Their analysis replicated studies of EFs in preschool children showing age-related changes (e.g., Diamond & Taylor, 1996; Hughes, 1998). The authors suggested that it is likely that maturational changes at both the biological and contextual levels are governing EF development, over and above children’s increasing comprehension of task rules and the verbal self-regulation needed to follow them. Additionally, within this cross-sectional
study by using logistic regression, Carlson (2005) established four scales that described
the relative difficulty level of each EF task and identified the different task demands
inherent in these measures. She found the difficulty scales that were produced showed no
consistent pattern of certain hot/cool task features of inhibition and working memory
demands being easier or passed earlier than others. However, in all age groups, the very
hardest tasks were those that were thought to involve a combination of inhibition and
working memory. The author suggests that the ways of fractioning EFs do not clearly
map onto age or difficulty levels. Instead, Carlson proposes that these divisions (hot/cool;
inhibition/working memory) might be most meaningful at the level of individual
differences regardless of age.

Barkley’s (1997; 2003) work suggests that adaptation is an important
consideration when thinking about developmental differences in EF processes. He
suggests that EFs serve the purpose of moving the individual away from socially-driven
behavior to self-regulation motivated by internal representations of the future. So, as EF
develops, the individual moves from externally-mediated regulation to internally-
mediated regulation. During infancy, the individual tends to respond to external objects
and events. As the child develops, increased motor and mental capacities facilitate
responses that are increasingly internally-determined and based on information that has
been gained about others and about the environment. For example, strategies employed
for the control of focused attention, or for guiding working memory processes, may
initially be implicit early in development.
Development of cognitive shifting.

The developmental course of cognitive shifting has been studied extensively in adults and more recently in young children. There is strong evidence to demonstrate the presence of shifting abilities in preschool children (e.g., Espy et al., 1999; Hughes, 1998; Jacques & Zelazo, 2001; Marcovitch & Zelazo, 2009). One frequently used measure is the Dimensional Change Card Sort (DCCS; Frye et al., 1995; Zelazo et al., 2003), in which children are asked to sort a series of colored shapes, first by one dimension (e.g., color) and then by the other (e.g., shape). Whereas 4-year-olds switch flexibly, 3-year-olds systematically perseverate on the preswitch rules during the postswitch phase, despite being able to describe the rules they fail to use (e.g., Bialystock, 1999; Carlson & Moses, 2001; Zelazo, Frye, & Rapus, 1996). In general, perseverative behavior is common in infancy, declines in early and middle childhood, and is rare in adolescence (Welsh et al., 1991). The capacity to switch rapidly between two response sets emerges between 3 and 4 years of age, but children in this age range have difficulty switching when rules become more complex (Espy, 1997; Zelazo et al., 2003). The ability to cope with these multi-dimensional switching tasks greatly improves between 7 and 9 years of age; however, 7-year-olds continue to struggle when switching between behaviors that are contingent on multiple dimensions (Anderson, 2002).

Zelazo et al. (2003) extensively studied the developmental changes in memory, inhibition, and shifting in preschool children using the well-validated DCCS (Frye et al., 1995; Zelazo et al., 1996) task. Multiple conclusions were drawn based on a programmatic series of nine different experiments. Among the most important findings
are: (a) most 3-year-olds perseverate on a task when required to shift rules, whereas most 4-year-olds switch flexibly; (b) 3-year-old children can use four rules to sort cards, showing that memory limitations do not constrain their performance on the DCCS; and (c) preschool children can use bidimensional rules when the rules are not in conflict; however, they have difficulty using a single pair of rules when they are conflicting, even if no switching of dimensions is required. In summary, the authors suggest that perseveration on particular rules is a function of rule complexity, and cannot be contributed to a general problem with inhibitory control. Thus, shifting abilities and working memory capacity in preschool children is highly dependent upon the rule complexity of a task and whether the rules are conflicting. The findings support age-related increases in the complexity of rules that children can formulate and use when solving problems. Lastly, the authors also highlight the importance of considering intentionality in the study of EF, suggesting that individual differences need to be accounted for when studying EF in young children.

The literature on the development of EF in young children is extensive. Similar to the theoretical foundations, research in the area of EF development spans across disciplines, and the measures, tasks, and assessments used to examine developmental trajectories also vary. The previous overview provided a compilation of research that supports the identification and delineation of cognitive shifting, inhibition, and working memory as three developing components of EF in preschool children. In the next section, an overview of the measurement of EFs in young children is described. However, due to the extensive variation in types of measurement methods utilized in research, depending
on the theoretical approach of the researchers, the focus will be on the broad conceptualization of the considerations and challenges to assessing EF in young children. Additionally, a particular focus on the measures used in this study will be referenced.

**Assessment of Executive Function in Young Children**

Historically, clinical assessment of EF in any age group has been challenging because of the individual’s fluid, dynamic nature (Nagle, 2007). This problem is particularly acute in preschool children, in part due to the variable nature of behavior and limitations in motor and verbal proficiency in this age range (Espy et al., 2001). Additionally, complication in measurement arises with such wide-ranging conceptualizations of EF. Several assessment tools have been developed to enable measurement of EFs in children and adolescents. The majority of tools are adaptations of measures originally developed for adults. For example, the *Delis Kaplan Executive Function System* (D-KEFS; Delis, Kaplan, & Kramer, 2001) includes many tasks thought to require the use of executive functions. As previously mentioned, many young children do not possess the motor, language or sustained attention skills needed to achieve success on those tasks. Thus, their “failure” on adult-oriented tasks has historically been viewed as evidence that young children do not possess EF skills. However, it is now well documented that beginning in infancy, EF skills develop and continue to develop throughout the preschool period. Recently, there has been a shift away from downward extension of tests used with adult populations and toward more developmentally sensitive measures for young children.
Executive function assessment approaches and complexities.

The assessment of EF in young children can be conceptualized within four approaches, depending on the nature and intention of use: (a) neuropsychological assessment batteries; (b) performance-based tasks; (c) rating scale measures; and (d) a combination of the previous three. First, the use of neuropsychological assessment batteries measure EF along with additional constructs of motor, sensory, attention, language, and visual processing. For example, the Developmental Neuropsychological Assessment, 2nd Edition (NEPSY-II; Korkman, Kirk, & Kemp, 2007) includes attention-executive subtests as one component of the battery. Other neuropsychological assessments have been developed for preschool children based on knowledge of brain-behavior relationships and neurodevelopmental theory (Williams & Monsma, 2007). The second approach utilizes performance-based tasks (i.e., A-not-B, digit span, delay gratification, see Carlson (2005) for a detailed description of preschool tasks), each of which are designed to measure a specific component of EF. These types of tasks are often used for the purpose of developmental research in order to further address measurement issues and identify age-related changes in EFs (Blair et al., 2005). A third approach that appears in the literature aims to measure a child’s EF skills from an ecological approach either within the context of their environment (e.g., Gioia et al., 2003) or through play (e.g., Transdisciplinary Play-Based Assessment-2; Linder, 2008; The Shape School; Espy, 1997; Espy, Martin, Bull & Stoup, 2006). Ecological validity in the assessment context refers to the “functional and predictive relation between the patient’s behavior on a set of neuropsychological tests and the patient’s behavior in a variety of real-world
settings” (Sbordone, 1996; p 16). Lastly, it should be understood that one goal of developmentally based assessment procedures is to capture emergent EFs in preschool children so that the earliest forms or precursors of neurological deficits or dysfunctions can be identified and described. Pennington (1997) emphasizes that tasks to measure discriminable executive processes are essential in order to help identify children affected with neurodevelopmental disorders that are considered to have unique profiles of executive dysfunction (i.e., ADHD, learning disabilities, or Autism Spectrum Disorders).

There are a number of complexities that arise in the measurement of EF in young children. Some of these complexities include test selection, interpretation issues, linking assessment to intervention, and developmental factors that contribute to behavior and learning. Some researchers have considered the extent to which change in EFs is a cause or a consequence of other cognitive and behavioral changes, such as changes in a children’s theory of mind (Hughes & Ensor, 2005), and the extent to which distinct processes and brain systems are at work in EF tasks that present some level of emotional arousal or aversive contingency versus those that are emotionally neutral (Hongwanishkul et al., 2005). Finally, the extent to which the characteristics of measurement stimuli are a determinant of performance in tasks requiring attention shifting has been considered (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005). However, despite the complexities mentioned, several assessment tools to measure EF have been developed for use with the preschool population (e.g., Espy & Cwik, 2004; Espy et al., 2006; Gershon & Zelazo, 2009; Gioia et al., 2003; Zelazo et al., 2003). The nature of EF measures varies depending on the conceptualization and application of their
use. In the following sections, a review of neuropsychological assessment batteries, performance-based tasks, and then three newly developed instruments based on an ecologically valid model are described.

**Neuropsychological assessment batteries.**

The NEPSY (Korkman, Kirk, & Kemp, 1998) and the D-KEFS (Delis et al., 2001) are the most widely used neuropsychological assessment batteries. They are comprised of several tasks that assess various EF processes, including selective attention, working memory, inhibition, planning, organization, and cognitive flexibility. For example, the Trail Making Test on the D-KEFS involves five conditions, including visual scanning and motor speed. This allows for the examiner to assess cognitive flexibility when the student switches between numerical and alphabetic sequences. Another open-ended task that focuses on a number of EF processes is the Tower Test, which is included on both the NEPSY and D-KEFS. This test assesses goal setting, planning, prioritizing, and self-monitoring. The difficulty with using these types of assessment batteries is that they have limited use with young children. The revised NEPSY, the NEPSY-II (Korkman et al., 2007) is standardized for use with children ages 3 and older; however, there are a limited number of subtests normed for use with the preschool population.

Meltzer & Krishnan (2007) suggest that other difficulties with these measures are that the tasks are brief, structured, and mediated by an examiner. They suggest that given the multidimensional nature of EF processes, it can be difficult to interpret the results of these discrete tasks and to link them directly to instructional strategies that help students to improve on tasks that require the application of EF processes.
**Task performance measures for young children.**

In the *Journal of Developmental Neuropsychology*, volume 28, six studies are presented that examine the sensitivity and utility of a variety of EF tasks for children as young as 2 years of age (Carlson, 2005; Espy, & Bull, 2005; Hughes & Ensor, 2005; Diamond et al., 2005; Hongwanishkul et al., 2005; Rueda et al., 2005). The use of scoring tasks as pass/fail to determine criteria for success is suggested as a developmentally appropriate approach to differentiate the emergence of EF skills (Blair et al., 2005; Carlson, 2005; Hughes & Ensor, 2005). These articles from this volume all propose that a central concern in the continuation of measure development is to further understand the demands of the regulation of behavior. Other performance-based tasks used to assess EF skills have included rule-governed, attribute-based sorting tasks (Hughes, 1998; Espy et al., 1999), including the DCCS task, manual selection or verbal naming of stimuli that conflict or interfere on the basis of natural associations (e.g., Day-Night Stroop; Carlson, 2005; Carlson & Moses, 2001; Diamond et al., 2002), manual search tasks with working memory demands (Diamond et al., 1997; Espy et al., 2001; Hughes, 1998), tower tasks (e.g., Tower of London; Bull et al., 2004; Shallice, 1982; Sikora, Haley, Edwards, & Butter, 2002), inhibiting prepotent or prohibited somatic motor responses (Carlson & Moses, 2001; Espy et al., 1999), and delay tasks (e.g., gift delay; Kochanska et al., 2000). The array of performance-based tasks used to assess EF skills in young children is extensive. In isolation, these tasks are most often used for developmental research; however a number of individual tasks are integrated into neurodevelopmental tests (i.e.,
Tower of London; Shallice, 1982) to measure the broader construct of EF for purposes of identifying executive *dysfunction*.

**Ecologically oriented measures for young children.**

Gioia and Isquith (2004) advocate for an ecologically valid model of EF assessment that explicitly incorporates two levels of information: (a) specific process components typically defined by clinical tests; and (b) real-world behavioral manifestations of the specific cognitive processes. Based on this model, Isquith et al., (2005) describe three newly developed instruments designed to assess EF in preschool children that meet these two aforementioned criteria. The Trails-P (Espy & Cwik, 2004) and the Shape School (Espy, 1997; Espy et al., 2004a; Espy et al., 2006) are two assessment tools that are designed to measure cognitive shift and inhibition in preschool children. Both tools have been shown to measure developmental differences in EFs and have demonstrated good psychometric properties (see Espy et al., 2006 for detailed psychometric descriptions). However, further evidence of validity for use with clinical populations is suggested (Isquith et al., 2005). The Trails-P and the Shape School are both described as promising tools to assess the processes involved in executive control in young children with neurological, psychiatric, and developmental disorders (Isquith et al., 2005).

Another assessment tool aimed to address the issue of ecological validity is the Behavior Rating Inventory of Executive Functioning-Preschool Version (BRIEF-P; Gioia et al., 2003). The BRIEF-P represents one of the first standardized rating scales designed to measure executive function in preschool children. Similar to its parent tool, the BRIEF
(Gioia, Isuith, Guy, & Kenworthy, 2000), the BRIEF-P utilizes parent and/or teacher behavioral reports to describe a full range of EFs. Isquith et al., (2004) have reported the BRIEF-P to be capable of identifying differences in EFs between clinical and control samples across all five domains. Although the BRIEF-P demonstrates information to suggest that behavioral manifestations in everyday routines can indicate cognitive capabilities, the authors recommended using a multi-level approach (i.e., a combination of test-based measurements and everyday behaviors) in evaluating the EF capabilities of children with developmental disorders, cognitive delay, or clinical/medical conditions (Gioia & Isquith, 2004).

In conclusion, assessment of EF in preschool children remains challenging for many reasons. First, children’s variable verbal, motor, and attentional abilities and likely variable EF development provide a limitation to measurement. Second, as with many psychological assessments, many of the methods and tools for measuring EFs, including many performance-based tasks, have been adapted or modified from tools originally designed for adults. The appropriateness in adapting these tools for use with young children is still being explored. Fortunately, a number of researchers have developed tools specifically for the use with young children. However, there remains need for further evidence of reliability and validity of these measures before they become useful in the clinical context where interpretation of findings is paramount. Finally, it is highly suggested that no single method, such as performance-based tasks or ratings scales, is adequate in isolation (Isquith et al., 2005). Research thus far indicates that the use of a multifaceted approach to assessing EF in young children is essential.
Executive Function and Bilingual Children

First, defining bilingualism can be difficult since individuals with varying bilingual characteristics may be classified as bilingual. There may be distinctions between ability and use of a language; variation in proficiency across the four language dimensions (listening, speaking, reading and writing); differences in proficiency between the two languages; variation in proficiency due to the use of each language for different functions and purposes; and variation in language proficiency over time (Baker & Jones 1998). People may become bilingual either by acquiring two languages at the same time in childhood or by learning a second language sometime after acquiring their first language (Ballentyne et al., 2008). The NCELA makes a clear distinction between children who are bilingual and children who are English Language Learners (ELL). English Language Learners are considered to be in the process of learning English, whereas someone who is bilingual is considered to be proficient in two languages (Ballentyne et al., 2008). As previously mentioned, the NCELA uses the term ‘dual language learners’ to describe young children who are acquiring two languages simultaneously. However, a similar characteristic among bilingual, ELL, and DLL children is that they typically have a larger productive and receptive vocabulary in one of the languages and their vocabulary in each language taken individually is usually less than that of a monolingual speaker of the same age (e.g., Bialystock, 1998). Many researchers agree that bilingualism is better described in terms of degree rather than as a categorical variable (e.g., Bialystock, 2001; Carlson & Meltzoff, 2008). However,
currently there are no accepted standards for classifying children on the basis of an objective bilingualism scale (Carlson & Meltzoff, 2008).

In terms of the implications for research, it is rarely possible to equate children who are bilingual, DLL, and monolingual on all variables aside from the number of languages they speak. Bialystock (2001) noted that parental education, literacy learning in the home, proficiency in each language, the settings in which the second language is used, and socioeconomic status (SES) tend to correlate with several factors that are likely to influence the course of social-cognitive development. Bialystock suggests that the limitations of equivalency need to be considered in any research study. Nonetheless, questions about the effects of bilingualism and dual language learning on executive function are imperative and deserve examination despite the limitations. The literature on the topic of EF and bilingualism is reviewed in order to gain a better understanding of current research and methodologies.

**Research on executive function and bilingualism.**

Studies on the cognitive abilities of bilingual children have primarily been concerned with identifying developmental differences between children who are monolingual and bilingual. Recent examinations of specific areas of cognitive functioning suggest that bilingual children display some higher level skills in contrast to monolingual children. These skills include a greater ability to inhibit attention to previous mental representation (Bialystock, 2001); superior performance on spatial problems (Bialystock & Majumder, 1998); and a greater ability to ignore misleading features of a number concept task (Bialystok & Codd, 1997). Recently, studies of EF in bilingual
children have examined differences in attentional control (Bialystock, 1999), inhibition (Bialystock & Martin, 2004) and working memory (Carlson & Meltzoff, 2008).

A review of research on cognitive differences between bilingual and monolingual children concluded that a pattern of evidence supports that specific intellectual abilities are enhanced in this population (Bialystok, 2001; Goetz, 2003). This analysis revealed that one aspect of executive functioning, inhibitory control, develops more rapidly in children with extensive bilingual experience. Bialystock (2001) proposed a theoretical analysis that bilingual children are advanced in the ability to control attention to perceptual or representational features of a problem. According to Bialystock, language intrusions are prevented in bilingual speakers by holding in mind the relevant language and inhibiting the nonrelevant language. Bialystock (1986) found that bilingual children performed slightly better than monolingual children on a metalinguistic task requiring children to ignore perceptual features of a stimulus. Bialystock (1999) reported that this advantage appeared to carry over to other cognitive domains, such as shifting, in research using the DCCS task, where bilingual children showed an advantage on post-switch tasks. In Bialystock’s (1999) research, preschool Chinese-English bilinguals performed significantly better than English monolingual speakers on the DCCS after controlling for differences in verbal ability. The developmental advantage was approximately one year, with 4-year-old bilingual children performing similarly to monolingual 5-year-old children. Further examination of this evidence was conducted in a recent study by Bialystock and Martin (2004). They replicated the basic finding and further specified that the bilingual advantage helps only in task versions that call for ‘conceptual inhibition,’
that is, resisting attention to the previously relevant feature (e.g., color). Similarly, Feng, Diamond & Bialystock (2005) also found evidence that children who are bilingual excel at working memory tasks even when the inhibition demands are relatively low (as reported by Carson & Meltzoff, 2008). A limitation to the previously mentioned studies is that the bilingual populations examined were primarily Chinese-English bilinguals with an unidentified SES. Additionally, the studies reviewed used the term bilingual to refer to children who had English proficiency that was similar to that of the monolingual children in the study.

Recently, Carlson and Meltzoff (2008) investigated the effect of bilingual experience on young children’s executive functioning in a previously unstudied language group (Spanish-English). They found evidence that children who are bilingual performed better on the DCCS than children who are monolingual after accounting for vocabulary differences. No differences were found between groups (bilingual, immersion, and monolingual) on inhibition tasks requiring delay gratification or suppressing a motor response, all of which can be construed as having relatively low working memory demands. These findings support previous research that children who are bilingual have a more advanced ability to inhibit prepotent responses that require use of working memory, previously referred to as conflict inhibition. It should be highlighted that there is a distinction between inhibition of attention to a mental representation (where there is a bilingual advantage) and inhibition of an action/motor response (where there is not).
Executive Function and Socioeconomic Status (SES)

There is some recent research that has evidenced the relation between socioeconomic status (SES) and EF (e.g., Ardila, Roselli, Matute & Guajardo, 2005; Betancourt, 2007; Carlson & Meltzoff, 2008; Mezzacappa, 2004; Noble et al., 2005). Ardila et al. (2005) found that parents’ educational level was significantly correlated with children’s performance on a variety of EF measures, and was significant across age groups (ranging from age 5 to age 14). Mezzacappa (2004) found that SES was a significant factor in children’s performance on EF measures of orientation (shifting) and attentional control (inhibition). Based on the results from this study, the author suggested that environmental factors may play a substantial role in the development of basic attentional processes and EFs. This suggestion, taken into account with previous research that has repeatedly documented that children who grow up under conditions of persistent socioeconomic disadvantage perform more poorly than socially advantaged children on measure of global cognitive functioning such as IQ and school readiness (NICHD Early Child Care Research Network, 2003), suggests consideration of the impact of SES specifically on EF.

In contrast to the research suggesting the negative impact on SES on cognitive functioning, Carlson and Meltzoff (2008) found despite SES, bilingual children continued to display an advantage on measures of shifting and inhibition. The author’s statistically examined for the effects of SES on the outcome of EF measures in preschool children. They found that bilingual children outperformed the other groups, despite their social disadvantage. This suggests that when bilingual children are not equally matched with
their monolingual peers on verbal ability and SES (as in the reality for many Spanish-English bilingual children in US schools today), they may be able to compensate or achieve the same ends by an alternative route, namely, as indicated by Carlson and Meltzoff, honing the cognitive operations involved in language switching. Research in the area of examining EF in a bilingual population (Spanish-English) with limited English exposure (i.e., preschool children from Spanish speaking homes who attend English-Spanish preschools), is limited. Carlson and Meltzoff (2008) provide the first study to examine EFs in the Spanish-English population. However, their sample is limited to bilingual children who have at least one parent who speaks English. The present study aims to expand this research to examine the effects of limited English exposure and low socioeconomic status on EF in preschool children.

**Early Childhood Mathematics**

Early mathematical skills play a fundamental role in children’s academic success. Recent studies suggest that several pre-kindergarten mathematics domains may be important indicators of school success (Claessens, Duncan, & Engel, 2009; Duncan et al., 2007). Using data from the Early Childhood Longitudinal Study, Claessens et al. (2009) concluded that knowledge of early numeracy, including knowing numbers and concepts of ordinality, and patterning at the entry of Kindergarten were the two most important predictors of 5th grade math outcomes. Perhaps surprisingly, these same pre-mathematics skills were also found to be important predictors of 5th grade reading outcomes. Using six longitudinal data sets, Duncan et al. (2007) reported similar findings that early math skills, specifically knowledge of early numeracy, were the strongest predictors of both
later reading and math achievement, followed by early language and reading skills and then attention skills. In 2002, the NAEYC and the NCTM collaborated on the development of a joint position statement on early childhood mathematics. The need for high-quality, challenging, and accessible mathematics education for 3- to -6-year old children was cited as a vital foundation for future mathematics learning. This recommendation is predicated on a firm understanding of the underlying metacognitive and cognitive processes that can facilitate early math development.

Recently, with an increase in research on early mathematics, a number of early mathematics domains have been identified as critical foundations in young children’s knowledge of mathematics. Klein and Starkey (2004) have identified four distinct early mathematics domains: (1) early numeracy, (2) arithmetic, (3) geometry/spatial reasoning and measurement, and (4) patterning and logical relations. Such concepts have been identified to reflect the earliest developmental concepts that preschool children can acquire (Clements & Sarama, 2007; Klein & Starkey, 2004). According to Klein and Starkey (2004), the domain of early numeracy encompasses object counting, counting a subset of objects, knowledge of number order, number comparison, ordinal number terms, and number reproduction. Arithmetic concepts include addition and subtraction with and without concrete objects, and two-set addition. Concepts within the geometry, spatial reasoning, and measurement domain include knowledge of shape names, shape matching, reasoning about triangle transformations, and non-standard measurement (i.e., larger, smaller, etc). Lastly, the domain of pattern and logical-relations includes concepts of pattern duplication, pattern extension, and ordering a series of objects. Clements and
Sarama (2007) have identified similar domains of early mathematics. They conceptualize early mathematics to include all of the concepts identified by Klein and Starkey (2004); however, they also emphasize subitizing, or the ability to instantly see how many, as a pertinent skill in the development of early mathematics. To date, the majority of the longitudinal research in Head Start has focused on the domains of early numeracy and patterning; however, there is some evidence to suggest that these other domains, including arithmetic and geometry/spatial reasoning and measurement may also be predictive of later mathematics achievement (e.g., Clements & Sarama, 2007; Clements & Stephan, 2003; Jordan, Hanich, & Kaplan, 2003; Lehrer, Jenkins, & Osana, 1998). However, no studies have examined the predictive relationship among the specific concepts of these four early math domains in relation to EF, which constitutes an important component of the proposed project.

These four early math domains have been identified as critical components of math achievement in low socioeconomic populations (Klein & Starkey, 2004). Children who live in poverty and who are members of linguistic and ethnic minority groups demonstrate significantly lower levels of achievement in math and other areas (Campbell & Silver, 1999; Denton & West, 2002; Hampden-Thompson, Mulligan, Kinukawa, & Halle, 2008; Starkey & Klein, 1992). Low-income children of prekindergarten and kindergarten age have been found to possess less extensive mathematical knowledge than same aged middle-income children (Denton & West, 2002; Hampden-Thompson et al., 2008; Klein & Starkey, 2004). This gap encompasses several critical aspects of pre-mathematical knowledge, including concepts of early numeracy, arithmetic, space and
geometry, measurement, and patterning (Klein & Starkey, 2004). Thus it is critical to further identify underlying cognitive components that may contribute to the development of these gaps in mathematical achievement, specifically in Head Start and DLL populations.

In several recent, comprehensive Head Start reports (U.S. Department of Health and Human Services, 2003; 2005), participating children have not been found to make significant gains in these critical early mathematical areas. Data from Head Start Family and Child Experiences Survey (FACES; U.S. Department of Health and Human Services, 2003) shows that in the year 2000 children entered Head Start on average at the 21st percentile in early mathematics, as defined as early numeracy, and left on average at the 23rd percentile. In the Head Start Impact Study (U.S. Department of Health and Human Services; 2005), no significant gains in early mathematics were found for 3- and 4-year-old children attending 383 randomly selected participating Head Start programs spread over 23 states. Such findings clearly indicate the need for a closer look at what factors might impact and further support mathematics development in early childhood Head Start populations. Important metacognitive process advances in recent years has led some to suggest that variation in early math skills might be closely related to the development of EF skills (Carr & Jessup, 1995; Desoete et al., 2001; Senn et al., 2004).

**Executive Function and the Development of Mathematical Abilities**

Many studies have demonstrated a direct association between EF skills and children’s early emerging and developing mathematical abilities across a wide age range (e.g., Bull, et al., 2008; Bull & Scerif, 2001; Espy et al., 2004b; Gathercole & Pickering,
2000; Mazzocco & Kover, 2006; McLean & Hitch, 1999; St. Clair-Thompson & Gathercole, 2006). The strength of these relationships has been suggested to differ with age from the preschool through the elementary school-age years (Brocki & Bohlin, 2004). For example, both Holmes and Adams (2006) and McKenzie, Bull, and Gray (2003) reported strong associations between young children’s mathematics achievement and visual working memory, but weaker associations between older children’s mathematics achievement and visual working memory. This was coupled with an increase in the importance of phonological, or verbal, working memory in the older children’s mathematics performance. The central importance of working memory in relation to children’s mathematical achievement has been identified (e.g., Bull et al., 2008; Gathercole & Pickering, 2000; Holmes & Adams, 2006; McLean & Hitch, 1999). Additionally, other EF skills, such as inhibition, shifting, and updating have also been identified in relation to children’s mathematical achievement.

A number of studies have tried to specify the functional relations between different aspects of EF components (e.g., inhibition, shifting, and updating) and their relationship to a range of numerical and mathematical skills. These studies show that in preschool children (Bull et al., 2008; Espy et al., 2004b), and in children around age seven (Bull & Scerif, 2001) and age 11-years-old (St. Clair-Thompson & Gathercole, 2006) inhibitory skills are predictive of math ability. More complex shifting skills have also been found to be predictive of performance in children 7-years-old and older (Bull, Johnston, & Roy, 1999; Bull et al., 2008; Bull & Scerif, 2001; McLean & Hitch, 1999). For example, in two correlation studies, Bull and colleagues (1999) and Bull and Scerif
(2001) found that the perseveration of response on the Wisconsin Card Sorting Task, which measures shifting abilities, was negatively correlated with mathematics ability. That is, the lower the math ability, the more difficult children displayed in shifting strategy or set. This study also found that inhibition and working memory accounted for a unique variation in mathematical performance in 7-year-old children, after controlling for the influences of reading proficiency and intelligence scores. Whereas this study (Bull & Scerif, 2001) reported a specific relation between executive functioning and mathematics performance independent of reading skills, it is clear that EF skills have been implicated in many aspects of learning, including language comprehension, reading, and writing (e.g., Gathercole & Pickering, 2000; Gathercole et al., 2004; Jarvis & Gathercole, 2003). In a recent study, Bull and colleagues (2008) found that in preschool children both inhibition and shifting were not only predictive of math achievement, but also predictive of reading achievement, suggesting that these EF skills are generic to learning academic skills rather than to one specific domain.

**Working memory.**

Several researchers (Bull & Scerif, 2001; Gathercole & Pickering, 2000; McLean & Hitch, 1999) have noted the role of working memory in mathematics in school-age children. Recently, a number of studies have investigated the existence of this relationship in young children (Bull et al., 2008; Espy et al., 2004b; Kyttala, Aunio, Lehto, Van Luit, & Haurtamki, 2003). Espy et al. (2004b) found that in preschool children, working memory accounted for significant variance in early mathematical proficiency, even when age, verbal intelligence, and maternal education levels were
controlled. However, working memory skills were correlated substantially with inhibitory control, limiting the amount of unique variance in emergent mathematical skills that could be accounted for by working memory. Bull et al., (2008) found that working memory in preschool-aged children was a significant predictor of math achievement in elementary school. Although these authors differentiated between verbal working memory and visual-spatial working memory, both were found to be significant predictors of math achievement, with visual-spatial working memory as being the strongest predictor.

**Phonological loop/verbal working memory.**

To recall, Baddeley (1986) described a model of working memory that included the phonological loop (verbal working memory), which assumes responsibility for storing and manipulating verbal information. Significant associations have been reported between children’s phonological loop capacity and their mathematics performance (e.g., Holmes, Adams, & Hamilton, 2008). Some studies have attributed individual differences in mathematical problem solving (particularly arithmetic) in school-age children to inefficiencies in the utilization of the phonological system (e.g., Adams & Hitch, 1997; Jarvis & Gathercole, 2003). In early childhood, the phonological loop is considered to be important for the acquisition of number facts in order to form networks of learned number facts in long-term memory. It is also thought to support the retrieval of number facts from long-term memory (Holmes & Adams, 2006). St. Claire-Thompson and Gathercole (2006) found that working memory and inhibition in school-age children both uniquely predicted curriculum attainment in mathematics and English, indicating that
these skills support general academic learning rather than the acquisition of skills and knowledge in specific domains. Similarly, Bull et al., (2008) found in preschool children that verbal working memory was a significant predictor of both math and English achievement, again suggesting that verbal working memory appears to be generic to learning rather than specific to learning in one particular domain.

**Visuospatial sketch pad/visual working memory.**

In Baddeley’s (1986) model of working memory, he also described the visuospatial sketch pad (VSSP) or visual working memory, which processes visual and spatial information. Recent research is placing more emphasis on the important role of the VSSP in children’s early mathematical skills (Bull et al., 2008; McKenzie, Bull, & Gray, 2003; Holmes & Adams, 2006; Holmes et al., 2008). Visual-spatial skills and visual-spatial working memory have been found to be related to children’s early counting ability and overall mathematical performance (Kyttala et al., 2003). Rasmussen and Bisanz (2005) reported that VSSP scores predicted unique variance in preschooler’s performance on nonverbal mathematics problems, suggesting they may use a mental model for arithmetic that requires the VSSP. Throughout the school years, VSSP scores have been shown to correlate significantly with standardized mathematics achievement at 7- (Gathercole & Pickering, 2000; Holmes et al., 2008), 9- and 10- (Homes et al., 2008; Maybery & Do, 2003), 11- and 14-years-old (Jarvis & Gathercole, 2003). Bull et al., (2008) found that the specific prediction of visual-spatial short-term memory to math achievement from preschool to age seven emphasizes the importance of a good understanding of spatial relations and the importance of being able to manipulate visual-
spatial material in working memory as critical to mathematical achievement. These results, along with results from Jarvis and Gathercole (2003) suggest that the inability to represent visual-spatial information in working memory may be particularly detrimental to early developing non-verbal numerical skills.

Evidence suggests that children with math disabilities have executive problems reflecting working memory (Jing, Wang, Yang, & Chen, 2004; McLean & Hitch, 1999; Wilson & Swanson, 2001), inhibition (van der Sluis, John, & van der Leij, 2004) and shifting (Bull & Scerif, 2001; McLean & Hitch, 1999; van der Sluis et al., 2004). Studies of children with specific mathematical difficulties have shown that they typically perform poorly on visual-spatial measures requiring use of visual working memory (Holmes et al., 2008; Kyttala, Aunio, & Hautamaki, 2010; McLean & Hitch, 1999). One of the identified subtypes of math learning disabilities includes those individuals believed to have deficits in visual-spatial skills (Mazzoco, 2007). Bull and Scerif (2001) propose that lack of inhibition and poor working memory are specific aspects of executive dysfunction that underlie mathematics learning disabilities. This relation between executive problems and math disabilities has generally been studied in children seven years and older. Further understanding of the relationship between these EF components and specific math skills in young children will help to advance early detection of math difficulties and opportunities for early intervention. This continues to be an area of exploration in the literature.

In conclusion, there is substantial evidence to support the relationship between executive functioning and mathematics abilities. Although this relationship in young
children is less explored, there is some evidence to support that working memory, inhibition, and shifting are associated with early emerging and developing mathematical abilities in preschool children (Bull et al., 2008; Espy et al., 2004b; Kytalla et al., 2010). However, the evidence remains unclear as to the specific relationship between these three EF skills and specific early math concepts (except early numeracy, as evidenced by Kyttalata et al., 2003), such as arithmetic tasks, space/geometry and measurement tasks, and pattern and logical relations tasks. Furthermore, considering that there is some evidence that bilingual children have advanced working memory and inhibitory abilities, the present study also aims to explore the relationship between these particular EF skills and mathematics abilities in a DLL population.

In review, the following are the research questions based on the literature, which are addressed in this study:

1. What is the convergent validity between the performance-based tasks of EF and the rating scale measure of EF for each of the three factors?
2. Are there differences in performance between ages, genders, and language groups on these executive function measures and on the four early math domains?
3. Does a performance-based measure of EF predict critical early math skills in the domains of early numeracy, arithmetic, geometry/spatial reasoning and measurement, and patterning and logical relations, when controlling for vocabulary ability and previous Head Start experience?
Chapter Three: Methods

Overview of Design

This research study was part of a larger project entitled *Enhancing Early Mathematics Learning and Assessment via Interactive Computer Games*, which used a quasi-experimental research design. In this larger project, nine classrooms from six Head Start centers (with children ages 3 and 4) were assigned to either a computer math game intervention group or a control group where classrooms continued with typical math instruction without any math computer games. For the larger project, the children were pretested in September and were post-tested following the intervention assignment.

For the purpose of the present study, three additional assessments were conducted during the initial pretest phase of the larger study. This study used an exploratory research design to examine data from the pretest phase of the larger project. Children were treated as both a within subjects group and a between subjects group depending on the research question and analyses utilized.

Sample

The children in this sample attended six Denver metropolitan Head Start centers that were recruited to participate in the larger study. Of the six Head Start centers, there were a total of nine classrooms. Thus, the sample for this research study came from these nine classrooms, which consisted of 98 preschool children who ranged in age from 3 years 1 month to 4 years 11 months ($M = 4$ years, 2 months, $SD = 6.76$ months, see Table
1 for details). Of these children, there were 50 boys (51%) and 48 girls (49%). Ethnic composition of the sample as reported by parents was 68% (n=67) Hispanic, 16% (n=15) Caucasian, 11% (n=11) African American, 3% (n=3) Mixed race, 1% American Indian (n=1), and 1% (n=1) Latvian. One child was excluded from the assessments because he was unable to physically participate due to multiple disabilities. Not all assessments were completed on all the children, and thus varying numbers are used for the analyses (see Table 2 for details).

Children who received parental consent were identified as either Dual Language Learners (DLL) or English speakers based on intake information obtained at each Head Start center. Upon entry to Head Start, parents are asked about the primary language(s) spoken at home. The DLL group included 42 children. In this group, all parents reported that English is not the primary language spoken at home (Spanish, n = 38, Arabic, n = 3, Russian, n = 1). The second group, the English group, included 56 children. All parents of children in this group reported English as their child’s dominant language at home. Additionally, 39% (n = 40) of the children had previously attended Head Start (answered as yes or no) and 11% (n = 11) of the children were reported to have an Individualized Education Plan (IEP).

A power analysis was conducted using NCSS Statistical and Power Analysis Software (Hintz, 2007) to determine the required sample size. It was estimated that 74 children would be adequate for a multivariate analysis of variance with three response variables for a power of .95, at a .05 significance level, and for a large effect size. For a multiple regression with three predictor variables, it was estimated that a sample size of
77 would be adequate for a power of .80, at a .05 significance level, and for a large effect size.

Table 1

**Demographics**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Overall</th>
<th>Language Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>DLL</td>
</tr>
<tr>
<td>Age (months)</td>
<td>50 (SD=6.8)</td>
<td>51 (SD=5.8)</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boys</td>
<td>50</td>
<td>21</td>
</tr>
<tr>
<td>Girls</td>
<td>48</td>
<td>21</td>
</tr>
<tr>
<td>Verbal Ability (PPVT/TVIP)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean (SD)</td>
<td>88.5 (SD=13.48)</td>
<td>82.55 (SD=13.13)</td>
</tr>
<tr>
<td>Range</td>
<td>52 – 188</td>
<td>52 – 118</td>
</tr>
<tr>
<td>Previous Head Start Total #s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>39</td>
<td>17</td>
</tr>
<tr>
<td>No</td>
<td>59</td>
<td>25</td>
</tr>
<tr>
<td>IEP Status Total #s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>No</td>
<td>87</td>
<td>40</td>
</tr>
<tr>
<td>Sample Size</td>
<td>98</td>
<td>42</td>
</tr>
</tbody>
</table>
Table 2

**Completed # of Assessments**

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Total # Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Child Math Assessment (CMA)</td>
<td>96</td>
</tr>
<tr>
<td>Peabody Picture Vocabulary Test, 4th Edition (PPVT)</td>
<td>96</td>
</tr>
<tr>
<td>Test of Vocabularie de Peabody (TVIP)</td>
<td>38</td>
</tr>
<tr>
<td>NIH Toolbox for Assessment of Neuropsychological and Behavioral Functioning (NIH Toolbox)</td>
<td>92</td>
</tr>
<tr>
<td>Behavior Rating Inventory of Executive Functioning -Preschool (BRIEF-P)</td>
<td>98</td>
</tr>
</tbody>
</table>

**Instruments**

**Peabody Picture and Vocabulary Test, 4th edition (PPVT-4).**

The PPVT-4 (Dunn & Dunn, 2007) was used as a variable to control for vocabulary knowledge; it was not used to identify group placement (DLL versus English). This was administered to all children in both groups, so that children in the **Dual Language Group** had a comparison score to be used with the Spanish version. It should be noted that for four out of the 42 children in the DLL group, Spanish was not their primary home language, so these children were administered only the PPVT-4 because receptive vocabulary tests were not available in their home language (e.g., Russian and Arabic).

The PPVT-4 is a standardized, individually administered test of English receptive vocabulary for use with children aged 2 years 6 months to 90+ years. The age-norm and grade-norm samples were designed to resemble the English proficient population and closely match 2004 Census data for demographic variables. The PPVT-4 is shown to have good psychometric properties. Correlation coefficients ranged from .82 to .92 with the Wechsler Intelligence Scale for Children – Third Edition verbal, performance, and full scale IQ scales. Reliability tests range from .91 - .98 (see Technical manual for more
psychometric details; Dunn & Dunn, 2007). To administer the PPVT-4, the experimenter reads aloud a word and children are asked to select the picture that best illustrates the word referred to among a set of four pictures. The items become more difficult as testing progresses. Standardized tables convert raw scores to percentiles and standard scores. For data analysis, the PPVT-4 standard score was used. Total administration time was between 10-15 minutes.

**Test de Vocabulario en Imagenes Peabody (TVIP).**

The TVIP (Dunn, Lugo, Padilla & Dunn, 1986) was also used to control for vocabulary knowledge. The TVIP is the Spanish version of the PPVT, and was co-normed with the PPVT-R version. It is a standardized, individually administered test of Spanish receptive vocabulary for use with children aged 2 years 6 months to 17 years 11 months. Reliability tests range from .91-.93 for ages 3 through 5-years. Total administration time is between 10-15 minutes. This assessment was administered to children for whom their primary language was Spanish. The composite standard score was used as the covariate for data analysis only if it was higher than the child’s score on the PPVT-4. It should be noted that of the 38 Spanish speaking children in the DLL group, 19 were unable to complete this assessment due to a lack of vocabulary knowledge in Spanish, and performed higher on the PPVT-4. In these cases the higher standard score was used for data analysis. This is discussed further, below.

**Child Math Assessment (CMA).**

The CMA (Starkey, Klein, & Wakely, 2004) is a standardized assessment tool designed to assess preschool children’s mathematical knowledge across a broad range of
concepts. This tool was chosen by the larger project to use as an assessment of children’s mathematics knowledge because of its comprehensiveness in the examination of the four critical early math domains. The CMA has been utilized in multiple studies as a standard assessment of children’s early math skills (e.g., Klein & Starkey, 2004; Klein, Starkey, Clements, Sarama, & Iyer, 2008; Starkey & Klein, 2008). The authors of the CMA report test-retest reliability over a 2-week interval as .91 and Cronbach’s alpha over all tasks as .90. Moreover, as evidence of convergent validity, CMA scores were found to be positively related to TEMA-3 scores (r = .74, p<.01) among 4-to 5-year-old children, including demographic variables of low SES and English Language Learners. For data analysis, the CMA total percent accuracy score was used.

The CMA has two versions: the original and the shortened versions. This study used the CMA –shortened version (see Appendix). Both versions of the CMA are standardized to be administered in either English or Spanish. The CMA –shortened version is composed of nine tasks (or subtests) that assess early mathematical knowledge in the areas of early numeracy, arithmetic, geometry/spatial reasoning and measurement, and patterning and logical relations. The tasks that assess early numeracy are Object Counting and Construction of Equivalent Sets. The tasks that assess arithmetic include One-set Addition and Subtraction, Two-set Addition and Subtraction, and Division. Tasks that assess geometry/spatial reasoning and measurement include Geometric Reasoning, Direct Measurement, and Shape Recognition. The patterning and logical relations domain includes Pattern Duplication. Each task includes multiple problems. The
total administration time was between 25-35 minutes. See Table 3 for a description of problems comprising each of the tasks.
Table 3

*Description of Child Math Assessment (CMA) Tasks*

<table>
<thead>
<tr>
<th>CMA Tasks</th>
<th>Description of problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Object Counting</td>
<td>Counted pre-constructed arrays of 3, 9, 15, and 30 objects</td>
</tr>
<tr>
<td>2 One-set Addition &amp; Subtraction</td>
<td>Determined the effect of an addition or subtraction to one set on the quantitative relation between one initial hidden sets</td>
</tr>
<tr>
<td>3 Geometric Reasoning</td>
<td>Identified matching sides of two congruent triangles in different spatial orientations (slide, rotation, and flip transformations)</td>
</tr>
<tr>
<td>4 Construction of Equivalent Sets</td>
<td>Reproduced sets of 3 and 7 objects from a model</td>
</tr>
<tr>
<td>5 Two-Set Addition &amp; Subtraction</td>
<td>Determined the effect of an addition or subtraction to two sets on the quantitative relation between two initial hidden sets</td>
</tr>
<tr>
<td>6 Direct Measurement</td>
<td>Created non-standard measurement units and used them to compare the lengths, weights, and heights of two objects</td>
</tr>
<tr>
<td>7 Shape Recognition</td>
<td>Selected target shapes to match model shapes (square, triangle, hexagon) from an array of similar shapes</td>
</tr>
<tr>
<td>8 Pattern Duplication</td>
<td>Duplicated ABAB or AABBAABB color patterns</td>
</tr>
<tr>
<td>9 Division</td>
<td>Divided 3 different number sets of objects by 2 or 3 divisors</td>
</tr>
</tbody>
</table>

Children’s performance on the CMA was recorded as one point given for each correct item. Scores were computed for each of the individual mathematics tasks, the four math domains, and for the CMA as a whole. Since the numbers of problems vary across tasks, a mean proportion correct for each of the 9 tasks was obtained by dividing the number of correct responses by the number of problems on that task. In addition to the individual task scores, a composite score for each of the four domains was computed by summing the mean proportion correct on the individual tasks that comprise the domain and a total composite mathematics score was computed by summing the mean proportion.
correct on all of the individual tasks and dividing by 9 (possible range, 0–1.00). This provided an overall measure of children’s performance on the mathematics assessment.

**Behavior Rating Inventory of Executive Function-Preschool (BRIEF-P).**

The BRIEF-P (Gioia et al., 2003) is a standardized rating scale for ages 2 through 5 years, that was derived from the original BRIEF (Gioia et al., 2000) developed for ages 5 through 18. The BRIEF-P consists of 63 items that make up five clinical scales and utilizes parent and/or teacher behavioral report to describe a full range of executive functions within the context of home and preschool environments. The five scales include: Inhibit, Shift, Emotional Control, Working Memory, and Plan/Organize (see Table 3 for a description of the scales). The scales yield raw scores, which were converted to standard scores and percentiles. For the purposes of this research study, standard scores for the scales of Inhibit, Shift, and Working Memory were used for data analysis because these are three factors of EF in preschool children that have been identified in the literature.

The standardization sample for the BRIEF-P reflected the population of the U.S. according to key demographic variables: gender, SES, race/ethnicity, age, and geographic population density. The authors of the BRIEF-P report excellent psychometric properties. Reliability reported ranges from .80-.97. Reliability is reported for the teacher ratings on the Inhibit scale as .94, the Shift scale as .90, and the Working Memory scale as .94, demonstrating excellent internal consistency. For further details on reliability and validity of the instrument, see the manual (Gioia et al., 2003). The total time to complete the BRIEF-P was estimated to take between 10-15 minutes.
Table 4

*Description of BRIEF-P Scales*

<table>
<thead>
<tr>
<th>Scale</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhibit</td>
<td>Measures a child’s inhibitory control and the ability to stop his or her own behavior at appropriate times</td>
</tr>
<tr>
<td>Shift</td>
<td>Measures a child’s ability to move from one situation, activity, or aspect of a problem to another, as the conditions require</td>
</tr>
<tr>
<td>Emotional Control</td>
<td>Measures a child’s ability to modulate his or her emotional responses as needed</td>
</tr>
<tr>
<td>Working Memory</td>
<td>Measures a child’s ability to hold information in his or her mind for the purpose of completing a particular task or making a response</td>
</tr>
<tr>
<td>Plan/Organize</td>
<td>Measures a child’s ability to manage current and future-oriented task demands within the situational context</td>
</tr>
</tbody>
</table>

**NIH Toolbox for Assessment of Neurological and Behavioral Function.**

As previously mentioned, this assessment battery was currently in the validation stages of development and thus the principal investigator collaborated closely with Phil Zelazo at the University of Minnesota Child Development Lab to ensure the fidelity of administration and scoring.

The NIH Toolbox was designed by Gershon and Zelazo (2009) to provide a standardized measure for which to assess executive function in individuals ages 3 through 90+. The battery is separated into two sections – one for children ages 3-7 and the other for individuals ages 7 and older. The battery for young children includes three tasks: inhibition, shifting, and working memory and was administered via a touchscreen monitor, in which children responded by touching a picture on the screen. The data analysis program, *Eprime*, was used to automatically calculate children’s response times and automatically tracks the children’s responses. The individual tasks have been developed to isolate specific components of EF by decreasing the demands of other
cognitive processes. The total administration time was approximately 20-25 minutes to administer. It was translated into Spanish by a graduate student for the Spanish speaking children. The three tasks of the battery are described in detail below.

**Dimensional Change Card Sort (DCCS) – shift.**

This task was developed based on the work of Zelazo et al., (2003) and provides a measure of cognitive shifting abilities. In this task, children are shown two target cards (e.g., a blue rabbit and a red boat) that vary along two dimensions (e.g., color and shape), and they are asked to sort a series of cards (e.g., red rabbits and blue boats), first according to one dimension (e.g., color, for which they are told, “If it’s blue it goes here; if it’s red it goes there”) and then according to the other (e.g., shape, for which they are told, “If it’s a rabbit it goes here; if it’s a boat it goes there”). For example, on the touchscreen the child sees a target picture in the top center of the screen and two boxes are displayed on either side of the bottom of the screen. One box has the matching picture by shape and the other box has a matching picture by color. On each trial the word “color” or “shape” is verbally stated and the child touches to the box that corresponds to the verbal prompt. For example, a red truck appears at the top center of the screen and at the bottom of the screen are a red crayon and a blue truck. If the verbal prompt “color” is given, then the child must touch the red crayon. If the verbal prompt “shape” is given, then the child must touch the blue truck.

The child is given four practice trials with feedback. The child must get at least 3 out of 4 practice trials correct in order to advance to the test trials. If s/he gets fewer than 3 out of 4 practice trials correct, s/he will complete a second set of 4 practice trials, with
the same cutoff in order to advance to the test trials. If s/he again does not meet the cutoff, there will be a final set of 4 practice trials. On this third set of trials, if the child does not meet the cutoff, the task will automatically terminate (i.e., will advance to final screen). The child will first complete a set of 5 test trials sorting, according to either shape or color (i.e., pre-switch phase). The child must get at least 4 out of 5 test trials correct in order to advance to the next set of test trials. If s/he does not, the program will automatically terminate. If s/he does, s/he will then complete a set of 5 test trials sorting by the other dimension. Again, the child must get at least 4 out of 5 test trials correct in order to advance; otherwise, the program will terminate. If the child meets criterion, s/he will then complete the mixed block, consisting of 50 shape/color trials (i.e., post-switch phase). This measure has been validated for use with preschool children to measure shifting and has been used extensively in research (e.g., Bialystock & Martin, 2004; Carlson & Meltzoff, 2008; Zelazo et al., 2003). For data analysis, two methods were used based on previous literature. First, pre-switch and post-switch accuracy scores were treated as separate variables, and second, a dichotomous variable was created which specified whether a child completed the pre-condition only or completed both the pre- and post-conditions. The remainder of this paper will use the acronym DCCS—shift when referring to this measure.

**Flanker – inhibition.**

The Flanker task was developed based on work by Rueda, Posner, and Rothbart (2005) and provides a measure of inhibitory control. On this task, the child is given four practice trials with feedback. Each trial begins with a central fixation point. The target
fish appears at the central fixation point, oriented either to the left or to the right (Figure 1, a and b). During the practice trials, five fish in a row are presented on the screen, and below are two boxes, one with an arrow pointing to the right and one with an arrow pointing to the left. The examiner prompts the child to “touch the arrow to match the direction that the middle fish facing.” The child must identify which direction the middle fish is pointing and touch the corresponding left or right arrow. After the examiner gives the direction once, only the verbal prompt “middle” is given for the remaining practice and test trials.

The child must get at least 3 out of 4 practice trials correct in order to advance to the test trials. If s/he gets fewer than 3 out of 4 practice trials correct, s/he will complete a second set of 4 practice trials, with the same cutoff in order to advance to the test trials. If s/he again does not meet the cutoff, there will be a final set of 4 practice trials. On this third set of trials, if the examinee does not meet the cutoff, the task will automatically terminate (i.e., will advance to final screen). During all of the practice trials, feedback is given to the child. For the test trials, there are two blocks, each containing 25 trials, 15 congruent (stimuli facing the same way), 10 incongruent (stimuli facing opposite direction from flankers) (Figure 1, c and d). In the first block, the stimuli consist of fish. The examinee must get at least 9 out of 10 incongruent trials correct in order to continue to the second block, in which stimuli consist of small arrows. If the examinee gets less than 9 out of 10 incongruent trials correct in the first block, the program will terminate. On this measure, inhibitory control was quantified by comparing accuracy and median reaction time between the reference condition involving congruent flankers and the
condition involving incongruent flankers. In the incongruent flanker task, children had to inhibit the tendency to respond to the direction of the flankers and respond instead to the direction of the target fish. It was expected that the interference created by these competing demands would increase both reaction time and commission errors. Results for all reaction time indexes take only correct responses into consideration. For data analysis, an efficiency score was calculated for each condition by dividing the number of stimuli correctly named by the latency to complete each condition. A total efficiency score was also calculated by dividing the number of stimuli correctly named by the total latency to complete the task. The remainder of the paper will use the term Flanker–inhibition to refer to this measure.
Figure 1. Examples of graphics used in the Flanker task, including (a) left-oriented target, (b) right-oriented target, (c) congruent flankers, and (d) incongruent flankers.

Self-Ordered Pointing Task (SOPT) — working memory.

The SOPT task provides a measure of working memory. This task was developed based on work by Petrides and Milner (1982) and was adapted from Hongwanishkul et al. (2005) for use with preschool children. In this task, the child is given a set of practice trials consisting of just 2 pictures, in order to familiarize them with the procedure. The child is given feedback on their responses. After the child touches a picture, the screen flashes to black, and then the pictures reappear in a rearranged format. The child is then
instructed to touch a “new” picture. This same sequence occurs for all trials, and the child is prompted each time to “touch to a new picture.” During the practice trials, if the child does not respond after 5 seconds on the first trial (i.e., the first time he or she sees the array of 2 pictures), he or she is prompted to do so by saying, “Touch one of the pictures!” The child is given 3 opportunities to pass the practice trials. If he or she errs on the first set of 2 pictures, he or she is given another set of practice trials with a new set of 2 pictures, and then a third set of practice trials if s/he errs on the second. Examinees must pass one set of practice trials in order to precede to the test trials; otherwise, the task will automatically terminate. Test trials start with a set of 3 pictures for children. Testing continues up to a maximum of 17 pictures. A discontinue rule is included for termination of the task. Working memory was quantified by the number of successful trials. The acronym SOPT – WM will be used to reference this measure.
Table 5

Overview of Executive Function Measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Stimulus Type</th>
<th>EF Component</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRIEF-P –I</td>
<td>Rating Scale</td>
<td>Inhibition</td>
</tr>
<tr>
<td>Flanker -inhibit</td>
<td>Nonverbal</td>
<td>Inhibition</td>
</tr>
<tr>
<td>BRIEF-P – S</td>
<td>Rating Scale</td>
<td>Shifting</td>
</tr>
<tr>
<td>DCCS –shift</td>
<td>Nonverbal</td>
<td>Shifting</td>
</tr>
<tr>
<td>BRIEF-P – W</td>
<td>Rating Scale</td>
<td>Working Memory</td>
</tr>
<tr>
<td>SOPT –WM</td>
<td>Nonverbal</td>
<td>Working Memory</td>
</tr>
</tbody>
</table>

Procedure

After approval from the Human Subjects Research Committee at the researcher’s institution, informed written consent was gathered from the parents and child oral assent was given at the time of each individual assessment. Following parental consent, the researcher conducted a brief training with each of the nine Head Start teachers on how to complete the BRIEF-P and a total of 108 forms were then distributed to the teachers. Upon completion of the BRIEF-P, teachers put the completed forms in a sealed envelope and the doctoral student collected the envelopes from each teacher. All forms were kept in a locked filing cabinet in the graduate student’s office to ensure confidentiality.

Assessment administration.

All child participants were tested individually by five female graduate school psychology students. Three of the graduate students had excellent conversational and grammatical fluency in Spanish and thus they were the experimenters who conducted the sessions with the children who were in the DLL group. The four children in the DLL group for whom Spanish was not their primary language were administered the assessments in English. The sessions took place in a quiet empty room within the Head Start centers. The math assessment and verbal assessments were administered in a fixed...
order as this is preferable to counterbalancing when investigating differences and correlations between variables (Carlson & Moses, 2001): Child Math Assessment (CMA; Starkey et al., 2004), Peabody Picture Vocabulary Test, 4th Edition (PPVT-4; Dunn & Dunn, 2007), and when applicable, the Test de Vocabulario en Imágenes Peabody (TVIP, Dunn et al., 1986). The executive function measure, the NIH Toolbox for Assessment of Neurological and Behavioral Function (Gershon & Zelazo, 2009) – DCCS – shift, Flanker – inhibition, and SOPT – WM, were administered at a separate time following the math and verbal assessment, which occurred in either Spanish or English, depending on the child’s primary language. All assessments were conducted within a four week period beginning the last week in August.

**Assessment training.**

A three day training occurred during the first week in August on the administration of the CMA. This training was provided as part of the larger study; however, the same student assessors were used for both research studies. This training included assessing for inter-rater reliability and required each student to mail in a video to the trainers in order to become certified to administer the CMA. To ensure fidelity of administration, a script in both English and Spanish was provided for the student assessors to follow. Following the training, the doctoral graduate student provided a one-day training to the five graduate student assessors on the administration the PPVT-4 and the TVIP (for those who spoke Spanish). Each graduate student was required to complete two practice administrations with a child and provide a video-taped administration session to the doctoral student in order to ensure competency in administration. In order
to ensure the fidelity of the assessment administrations, two meetings with the graduate student assessors were conducted: one occurred after the assessment administrations of week 1 and the second occurred after the assessment administrations of week 3. The meetings provided opportunity to review assessment procedures, discuss administration questions, and to provide a time for evaluating what has been accomplished and what still remained to be accomplished. Additionally, to ensure fidelity of administration, an English and Spanish script was provided for all assessments.
Chapter Four: Results

All statistical analyses reported were two-tailed, alpha levels set to .05 (unless otherwise specified), and effect sizes reported as partial eta squared.

Preliminary Analyses and Overview of Data Analytic Approach

The data set was examined for outliers and violations to the assumptions for multivariate normality. Univariate normality was assessed through SPSS, which yielded measures of skewness that ranged from −.38 to 1.70 and measures of kurtosis that ranged from −1.9 to 2.96. As such, all variables except one met standards of univariate normality as outlined by Field (2005). The DCCS- shift post-switch variable showed a non-normal distribution, which resulted from 86% of the children whom received a score of zero, meaning they did not pass the pre-condition. Thus, only the DCCS –shift condition variable (pre- condition only or pre- and post-conditions) was used for all further analyses and analyzed as a nominal variable.
Inter-correlations together with the means and standard deviations for all analysis variables are presented in Table 6. Pearson’s Product Moment Correlations, point-biserial correlations, and phi coefficients are reported depending on the type of variable.

First, results from the preliminary analyses for vocabulary score, IEP status, CMA data, and demographic correlations with the dependent measures are presented in order to
validate use of covariates in the regression model. Then, results for each of the three primary research questions are addressed.

**Vocabulary knowledge.**

As expected from past literature (e.g., Bialystok, 2001), the DLL and English groups differed significantly on verbal ability (the PPVT-4/TVIP), $t(94) = 3.89, p < .0001$ (see Table 1 for means and SDs). Children in the DLL group performed lower than children in the English group. Thus the PPVT/TVIP scores were used as a covariate for later regression analyses.

**IEP status.**

In order to determine if children with an IEP were to be included in the analyses, a series of independent sample $t$-tests indicated that there were no differences between children who have an IEP versus those that do not on their total CMA scores, or their performance on any of the executive function task measures (DCCS –shift, Flanker – inhibition, SOPT –WM). The Levene’s statistic showed non-significance, indicating that the assumption of equal variances was met for each variable. Based on these results, all 11 children with an IEP were included in all analyses.

**Child Math Assessment.**

Scores for the CMA are presented as total percentages correct, as suggested by the CMA authors. The CMA mean proportion correct was 28% ($SD = .15$), early numeracy ($M = .38, SD = .28$), arithmetic ($M = .27, SD = .17$), geometry/spatial reasoning and measurement ($M = .32, SD = .20$), and patterning/logical relations ($M = .08, SD = .21$). The two CMA domains of *early numeracy*, and *patterning & logical reasoning*, which
were not intended to be analyzed individually, displayed non-normal distributions. These domains with skewed distributions resulted from children who were unable to successfully complete the problems. On the early numeracy tasks, the skewed distribution resulted from 36% of the children who completed 0 – 10% of the problems correctly. On the patterning & logical reasoning tasks, the skewed distribution resulted from 86% of the children who completed zero problems correctly. Although these variables were not intended to be analyzed individually, they do contribute to the CMA mean proportion correct (which displayed a normal distribution) and are discussed in the following chapter in reference to early mathematical knowledge.

**Demographic correlations with dependent variables.**

The correlations between executive function scores, math scores, and pertinent sample characteristics including age, gender, IEP status, previous Head Start experience, and vocabulary knowledge are presented in Table 6. As expected, several of the executive function scores and the CMA score were significantly correlated to age, vocabulary knowledge, and previous Head Start experience. Gender was correlated with only one EF score, and IEP status was correlated with two of the EF rating scale scores. Given this pattern of results, age, vocabulary knowledge, and previous Head Start experience were included as control variables in later regression analyses.

**Executive Function Correlations– Question 1**

In order to examine the relationship between the performance-based tasks (NIH Toolbox) and the rating scale measure (BRIEF-P) of EF, Pearson’s correlations were conducted for each of the three components of EF. The magnitudes of the correlations
were moderate (see Table 6) and it should be noted that all correlations with the DCCS – shift condition used point-biserial correlations. The BRIEF-P Inhibition score was significantly correlated with the Flanker – inhibition score, \( r(90) = -.30, p = .005 \), and also significantly correlated with the DCCS – shift score, \( r(90) = -.28, p = .006 \). The BRIEF-P Shift score was not correlated with any of the performance-based tasks. The rating scale BRIEF-P WM score was significantly correlated with the SOPT – WM score \( r(90) = -.21, p = .05 \). Results indicated there were significant correlations among some of the performance-based tasks. However, the magnitudes of the correlations were small. The DCCS – shift task was significantly correlated with the Flanker – inhibition task, \( r(90) = .32, p = .003 \), and the SOPT – WM task, \( r(90) = .36, p < .001 \). Finally, the Flanker – inhibition task was correlated with the SOPT – WM task, \( r(90) = .38, p < .001 \).

**Group Differences on Executive Function and Math Measures— Question 2**

In order to examine group differences in performance on the executive function measures and the CMA, a series of analyses were performed including a multivariate analysis of variance (MANOVA) and three Chi-Square tests. First, scores from the Flanker – inhibition task, the SOPT – WM task, and the CMA were entered into a multivariate analysis of variance with age, gender, and language group as the between-subjects factors. Box’s Test of Equality showed non-significance, indicating that homogeneity of covariance matrices was equal and the assumption is tenable. MANOVA results showed a significant main effect for age, \( F(3,80) = 8.22, p < .0001, \eta^2 = .24 \), but not for gender, language group, or for any interactions.
A follow-up of the univariate test statistics was completed. The assumption of homogeneity of variances was met based on Levene’s statistic, which showed non-significance for all three dependent variables. Consistent with prediction, the univariate tests revealed that 4-year-olds scored higher on the Flanker–inhibition task, $F(1, 89) = 13.17, p = .001, \eta^2 = .14$; on the SOPT–WM task, $F(1, 89) = 15.79, p < .0001, \eta^2 = .16$; and on the CMA, $F(1, 89) = 18.54, p < .0001, \eta^2 = .18$. All effect sizes ranged from $\eta^2 = .14$ to .18, which according to Cohen’s (1988) rule of thumb, are small effect sizes. The univariate tests also revealed a significant difference between language groups on the inhibition task, $F(1, 89) = .04, p = .04, \eta^2 = .05$, though this significance was not detected in the more conservative multivariate test and thus is interpreted with caution. No contrasts were carried out because no groups had more than two levels.

In order to examine group differences between ages, genders, and language groups on the DCCS–shift task, three separate chi-square tests were performed. These analyses examined if there were group differences between those that completed only the pre-switch condition versus those that met criteria to complete the post-switch condition. The total number of children to complete each condition by group is displayed in Table 7. As suggested by Field (2005), Odds ratios are reported for each chi-square as a measure of effect size for each 2 x 2 contingency table. Consistent with the literature, the chi-square analysis showed a significant association between the age and the level of condition completed, $\chi^2(1) = 12.16, p < .0001$. All expected frequencies were greater than 5, indicating that this assumption for the chi-square was met. Based on the Odds ratio for this sample, 4-year olds were 8.05 times more likely to complete the post-switch
condition than 3-year olds. A significant association resulted between gender and the level of condition completed, $\chi^2(1) = 4.12, p = .04$, with girls in this sample being 7.5 times more likely to complete the post-switch condition than boys ($OR = 7.5$). A significant difference also emerged between language groups and the level of condition completed, $\chi^2(1) = 5.25, p = .02$. Based on the Odds ratio for this sample, children in the DLL group were almost three times more likely to have completed the post-switch condition than children in the English group.
Table 7

Total Number of Children Who Completed Each DCCS Condition

<table>
<thead>
<tr>
<th>DCCS Condition</th>
<th>Age</th>
<th>Language Group</th>
<th>Gender</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3(^b)</td>
<td>4(^b)</td>
<td>English(^c)</td>
</tr>
<tr>
<td>pre-condition only</td>
<td>35</td>
<td>32</td>
<td>42</td>
</tr>
<tr>
<td>pre- post-conditions</td>
<td>3</td>
<td>22</td>
<td>9</td>
</tr>
<tr>
<td>Sample size</td>
<td>38</td>
<td>54</td>
<td>51</td>
</tr>
</tbody>
</table>

Follow up analyses to question 2.

Based on the results that indicated there were differences both between age groups and between language groups on the DCCS –shift, further analyses were conducted to determine if there was an interaction between age and language on the DCCS –shift task. In order to enter the data into the analysis, a new variable was created with four levels to include both age and language group: (1) 3-year-olds/English, (2) 3-year-olds/DLL, (3) 4-year-olds/English, and (4) 4-year-olds/DLL. Figure 2 displays the number of children in each category who completed each condition on the DCCS –shift task. A chi-square analysis showed a significant association between the DCCS –shift condition and the age/language group of the child, $\chi^2(3) = 15.98$, $p = .001$. All expected frequencies were greater than 5. Based on an examination of the percentages from the results of the crosstab, 28% of children who were 4-years old/English completed the pre- and post-conditions, whereas 51% of 4-years old/DLL completed the pre- and post-conditions. To determine if this was a significant difference, these two levels were entered into a chi-square. Results showed that the Fisher’s Exact Test was not significant.
Figure 2. Number of children who completed each condition on the DCCS—shift task.

Executive Function as a Predictor of Early Mathematics—Question 3

To test the study question regarding whether different EF components predict early mathematical skills, several hierarchal regression analyses were conducted. First, each EF component score was entered in the regression model after controlling for age, with separate analyses for each EF component (three models with two steps in each model). This was done in order to examine the relations prior to controlling for vocabulary knowledge and previous Head Start experience, which was then compared with subsequent regression models to see if the relations persisted when the influences of two covariates were included in the models. Second, similar models were run with each EF component score entered stepwise (based on the magnitude of the bivariate correlations—working memory, inhibition, shift) after age and the other covariates (i.e., vocabulary score and previous Head Start experience) that were included as a block. A third set of hierarchal regression analyses were conducted to determine the relative
contribution of each executive function score beyond that of the two other executive function scores (e.g., unique contribution of working memory to early mathematical skills, beyond that of inhibition and shifting skills), models included age and the two covariates, then the two remaining executive function scores, and finally the executive function component of interest. Finally, for exploratory purposes, a hierarchal regression was completed in order to examine the unique contribution of vocabulary score and previous Head Start experience on children’s early mathematical proficiency.

The results from the regression analyses relating performance on the executive function tasks to early mathematical skills are presented in Table 8, Table 9, and Table 10. Data screening indicated all assumptions for regression analysis were met. No substantial correlations among predictors were evident and all variance inflation factor (VIF) values were less than 10, indicating that the assumption of multicollinearity was met (Myers, 1990). Based on the Durbin-Watson statistics, the assumption of independent errors is tenable for all models, and both linearity and homoscedasticity assumptions were met based on an examination of the residual plots.
After statistically controlling for the influence of age, higher scores on the Flanker–inhibition task and on the SOPT–WM task predicted greater mathematical proficiency on the CMA, $F(1, 89) = 16.62, p < .0001$, and $F(1, 89) = 48.56, p < .0001$, respectively. Additionally, after controlling for the influence of age, mathematical proficiency on the CMA was also influenced by the condition completed on the DCCS–shift task, $F(1, 89) = 6.40, p = .01$ (see Table 8). The relations of inhibition and working memory on children’s mathematics proficiency persisted when the influences of the two covariates, language score and previous Head Start experiences, also were included in the model; for inhibition, $F(1, 89) = 9.12, p < .003$, and for working memory, $F(1, 89) = 21.84, p < .0001$ (see Table 9). In both models, the working memory score accounted for the largest portion of variance in preschool mathematical skills, 29% in the only age-controlled model and 12% in the age- and covariate-controlled model. The inclusion of the covariates affected the relation between the inhibition task performance and early mathematical skills more than that of working memory task scores and mathematics, as...
the differences in the proportion of variance attributed to inhibition was reduced by 80% between the two models, in contrast to a 55% reduction for working memory. The magnitude of the standardized regression coefficients indicated that the differences in CMA proficiency was 42% correct between children who scored at the mean (expected score = 3.4) on the working memory task and those who scored 1 SD below the mean (expected score = 1.09) after controlling for child age, vocabulary score, and previous Head Start experience. Correspondingly, the difference in expected score on the CMA between children who scored at the mean on the inhibition task and those who scored 1 SD below the mean was 24% correct. The relation between shifting and children’s mathematics proficiency was not substantial after controlling for the influences of the additional two covariates.
Table 9

Contributions of EF Components to Early Mathematical Skills – Controlling for Age, Vocabulary Knowledge, Previous Head Start Experience (n = 92)

<table>
<thead>
<tr>
<th>Model Steps</th>
<th>B</th>
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<th>β</th>
<th>R²</th>
<th>ΔR²</th>
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<td>4. Age</td>
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<td>Flanker – Inhibition</td>
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</tbody>
</table>

*p < .05, **p < .01, ***p < .0001.

Because scores on the executive function tasks were intercorrelated, further analyses were conducted to examine the unique contribution of the inhibition and working memory tasks, beyond that of the remaining executive functions (see Table 10). The models included age, the two covariates, the remaining two executive function task scores, and finally, the executive function task of interest. These results are displayed in the bottom of Table 10. Performance on the working memory task accounted for unique variability (7%) in early mathematical abilities on the CMA, beyond that of both inhibition and shifting scores, $F(1,89) = 14.2, p < .0001$. Performance on the inhibition task accounted for 4% of the variance in early mathematical abilities on the CMA, beyond that of both working memory and shifting scores, $F(1, 89) = 7.78, p = .007$. 

91
Performance on the shift task was not related independently and uniquely to early mathematical abilities (as shown in Table 9, Step 4).
Table 10

**Unique Contributions of Each EF Component to Early Mathematical Skills Beyond Other Two EF Components (n = 92)**

<table>
<thead>
<tr>
<th>Model Steps</th>
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<th>R²</th>
<th>ΔR²</th>
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<td></td>
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<td>.00</td>
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<td>.02</td>
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<td>Flanker –Inhibit</td>
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<td>Flanker –Inhibit</td>
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<td>.61**</td>
<td>.04**</td>
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</table>

*p < .05, **p < .01, ***p < .0001.

**Additional influences on children’s mathematical knowledge.**

Finally, a hierarchal regression analysis was conducted to examine the unique contribution of vocabulary score to children’s early mathematical skills. Table 11 displays the results of the hierarchal regression. After statistically controlling for the influence of age, higher vocabulary scores were significantly related to higher performance on the CMA, $F(1,95) = 31.5, p < .0001$ and accounted for 21% of the variance. This relationship persisted when controlling for previous Head Start experiences, $F(1,95) = 29.72, p < .0001$, and continued to accounted for a unique variability (20%) in early mathematical abilities.
<table>
<thead>
<tr>
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<th>R²</th>
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*Note.* *p* < .05, **p* < .01, ***p* < .0001.
Chapter Five: Discussion

The aims of the present study were to assess the convergent validity between a third-party rating scale of EF (the BRIEF-P) and a performance-based task measurement of EF (the NIH Toolbox); examine the effect of age, gender, and dual language experience on young children’s executive functioning and early mathematical skills; and determine the amount of contribution that three EF components have on early mathematical skills.

By examining correlations between two different EF measures, this study addresses the discussion about the stability of these measures and about the assessment of EF in young children. By examining the effects of age, gender, and language group on the EF measures and the math measure, this study confirms age-related differences in EF and early mathematical abilities, and supports the growing body of evidence that EF abilities differ in DLL populations. Finally, by examining the contribution of EF skills and vocabulary knowledge to children’s early mathematics skills, this study contributes to the discussion regarding the influence of executive function skills and vocabulary knowledge on learning. Additionally, this study offers new insights regarding the interplay of dual language learning, EF, and the acquisition of early mathematical skills. Prior to addressing each of these issues in depth, a review of the preliminary findings takes place in order to help facilitate further discussion about the results.
Preliminary Analyses – Descriptive Data

Vocabulary Knowledge.

Consistent with the literature, children’s receptive vocabulary, as measured by the PPVT- 4, differed between DLLs and monolingual English speaking children (e.g., Bialystok & Martin, 2004). Due to the limitation of current research that delineates the terms DLL and bilingual, this discussion draws upon previous research that uses the term ‘bilingual.’ As previously mentioned, the majority of studies that have examined the relationship between EF and language have used the term bilingual to refer to children who are proficient in two languages (e.g., Bialystock, 2001). In contrast, the term bilingual has also been used to reference children who are learning a second language or who are categorized as English Language Learners (e.g., Hammer, Lawrence & Miccio, 2008).

Preschool children who are bilingual typically have a larger productive and receptive vocabulary in one of the languages and their vocabulary is usually less than that of a monolingual child of the same age (Bialystock, 1988; Oller & Eilers, 2002). This is also supported to be true for children who are DLLs (Ballantyne et al., 2008). Interestingly, in this study, 19 out of 38 children in the DLL group scored higher on the English receptive vocabulary test than the Spanish receptive vocabulary test. This may be due to a common phenomenon known as language attrition that is observed in many bilingual children who live in primarily monolingual environments and speak non-majority languages (Anderson, 2004). This is particularly true when children move from their home environment in which they speak a non-majority language into a school.
environment and speak a majority language. Thus, children experience changes in the input that they receive as well as reduced opportunities to speak their home language (Hammer et al., 2008). For example, Latino children in the U.S. may go from a home in which both Spanish and English are spoken or a home in which only Spanish is spoken to a school environment where English is the primary language used for communication. As a result, children may receive fewer opportunities to hear Spanish, acquire Spanish vocabulary and speak Spanish with adults and peers (Anderson, 2004).

Although this is a topic of discussion and further research, it is important to consider this issue as being interrelated with executive function and the acquisition of early mathematical skills for a number of reasons. First, some researchers theorize that for children who are DLLs, one of the languages must be constantly inhibited to prevent on-going intrusions and acquire new language skills (Bialystock, 2001; Green, 1998). Other researchers suggest that as two languages are co-developing, individuals are constantly code-switching and translating between the two languages (Chee, 2006). Second, early literacy and vocabulary skills have been found to be related to general mathematical performance in 4- to 5-year old children (McLelland et al., 2007). In elementary school, language skills are observed to be related to the development of single-digit arithmetic skills (Koponen, Aunola, Ahonen, & Nurmi, 2007) and solving math word problems (Fuchs et al., 2006). Additionally, Donlan, Cowan, Newton & Lloyd (2007) found that children with specific language impairment (SLI) seem also to have specific deficits in certain mathematical areas, such as production of the number word sequence, basic arithmetic performance and in understanding place-value. A clear
connection can be drawn between vocabulary and mathematics. Children must possess the vocabulary knowledge in order to understand and apply fundamental mathematical concepts and communicate their thinking (Charlesworth, 2005). Preschool children’s oral language skills and their understanding of symbols such as letters and numbers are developing at a rapid rate. Concept vocabulary increases and is applied through adult comments and questions: “Can you get the orange ball?” “How many cars do you have?” or “Point to something that is square”. Hence, language (including vocabulary) and mathematics are inextricably linked.

IEP status.

In this study, children with IEPs did not differ from those without IEPs on the PPVT-4, on any of the EF measures or on the CMA. Although this is not a topic of focused discussion, it is important to note because one, these children were included in the sample, and two, this could provoke conversation as to why and/or how children are identified to qualify for an IEP.

For this sample, the qualifying factors for children with IEPs were not known, thus it makes it difficult to draw any conclusions about this small group. However, one possible explanation for the findings that children with IEPs did not differ from those without could be related to the disproportionate representation of diverse students in special education. Data from the Twenty-Second Annual Report to Congress on the Implementation of the Individual with Disabilities Education Act (Office of Special Education and Rehabilitation Services [OSERS], 2000) was analyzed by Parish (2002) who reported that Hispanics were 17% more likely to be identified with a learning
disability when compared to white students, and that this percentage varied across states (ranging up to 239% greater probability) depending on the percentage of the ethnic population. Interestingly, authors from this annual report found different trends when examining racial/ethnic characteristics of infants, toddlers, and preschoolers served under Part C of IDEA (OSERS, 2000). Given that early intervention services are critical, school districts are required to undertake activities (e.g., Child Find) to help identify these children and provide services to them. However, the data in this report indicate that Hispanics are being underserved by Part C of IDEA (OSERS, 2000). Thus, the over- and under-representation of children in special education may be one explanation as to why there were no differences between the groups in this sample.

**Child Math Assessment.**

A brief discussion on the preliminary analyses of the CMA data is important to consider in regards to preschoolers’ mathematical knowledge in this Head Start sample. Performance on the CMA for this sample was similar to previous findings that used the CMA with children from low SES homes (Klein, Starkey, Molfese, Brown, & Molfese (2009). It is important to note that a large percentage of children were unable to complete any of the tasks on the early numeracy domain, and on the patterning and logical relations domain. Considering that the National Council of Teachers of Mathematics published a set of standards that include fundamental prekindergarten concepts and skills that children should acquire between 3- and 4-years of age (NCTM, 2000), the results from this sample suggest that these children have not yet acquired some of the fundamental concepts. Certainly, it is essential to consider previous Head Start experience when
interpreting these data, and that the assessments were conducted at the beginning of the school year. It was found that for this sample, there was a significant difference in performance on the total score of CMA between children who had previous Head Start experience versus those that did not. This would be expected; however, it is critical to consider the impact of age and language development on children’s mathematical knowledge (as discussed further, below). It is not clear what factors contributed to the difference in performance on the CMA between these two groups.

Interestingly, there was no significant difference on the patterning and logical relations domain between children who have had previous Head Start experience versus those that did not. One possible explanation for these findings may be that the children in this sample have had little exposure or opportunities to develop early mathematical skills across domains. According to Copley (2004), many public preschool programs serving low-income families, as compared to private programs serving middle-income families, provide fewer learning opportunities and supports for mathematical development. In general, pre-kindergarten teachers do not use a systematic math curriculum, receive little or no training in early childhood mathematics, are unfamiliar with the math curriculum taught in local elementary school, and know little about math standards (Copley, 2004).

Additionally, research on the home learning environment has examined parental practices for supporting early mathematical development. In a study of Head Start families, Klein and Starkey (1995) interviewed parents of low-income families and found that most parents reported practices that supported oral counting and sometimes numeral recognition or shape naming, but rarely reported practices related to broader areas of
Another study revealed considerable differences between families of different SES in their home mathematics practices, with middle-income parents more likely to provide a range of mathematical activities than did low-income parents (Starkey et al., 1999). Thus, it is feasible to assume that these explanations (lack of mathematical learning opportunities at both home and school) contributed to children’s performance on the CMA.

A second explanation for these findings may be attributed to the limitations of the CMA. An uneven number of tasks contributed to each domain, with the least number of tasks in the patterning and logical relations domain. Thus, children had fewer opportunities to demonstrate knowledge in this domain. These findings from the CMA results offer further support for the need to provide greater effective instruction to preschool children, particularly in Head Start. This is especially important for low-income children who receive minimal support for mathematical development in their learning environments (Copley, 2004; Klein & Starkey, 1995; Starkey et al., 1999). One approach to enrich the preschool learning environment is to provide a systematic mathematics curriculum, which includes professional development, teacher collaboration, and home-school communication. Starkey et al. (2004) have suggested that reliance on a general early childhood curriculum to support the specialized area of mathematical knowledge across domains is a pedagogically risky approach, and recommend that children, especially in programs serving low-income families, receive time- and place-specific mathematics curriculum with teacher scaffolding.
Following these preliminary findings, which offer important insights about vocabulary and early mathematical knowledge, the three research questions of interest are discussed.

**Executive Function Correlations—Question 1.**

One aim of the current study was to examine the convergent validity between three clinical scales on the BRIEF-P and three performance-based tasks on the NIH Toolbox. Authors of previous research using the BRIEF-P have consistently demonstrated high correlations with other rating scale measures, such as the ADHD Rating Scale–IV Preschool Version, the Child Behavior Checklist 1½-5 Parent Form, and the BASC (e.g., Gioia et al., 2004), but have not demonstrated correlations with other performance-based tasks that measure EF. The results from this study demonstrate correlations among some of the measures; however, a number of major issues in EF measurement remain.

Specific correlations between EF components are discussed and are followed by possible explanations and implications for practice. Correlation analyses revealed that the BRIEF-P inhibit scale and the Flanker –inhibition task were related. This suggests that as children’s efficiency scores on the Flanker –inhibition task increased their scores on the BRIEF-P decreased. This negative relationship would be expected, as higher efficiency scores on the Flanker –inhibition task represent a combination of increased accuracy and reaction times and lower scores on the BRIEF-P inhibit scale represent a child’s inhibitory control as expected for that age. The BRIEF-P inhibit scale was also related to the DCCS –shift task in an inverse relationship. This suggests that children who were
perceived as having typical abilities (as compared to same age peers) to control their behaviors when appropriate were more likely to have the shifting skills necessary to complete the post-switch condition. In other words, as a child demonstrates self-control (i.e., not knocking over another child’s block tower), they must simultaneously be able to shift attention between their choices (i.e., I could knock over this tower or I could not knock over this tower) while also beginning to evaluate the consequences of their actions. Interestingly, the BRIEF-P shift scale and the DCCS- shift task were not related. And finally, the BRIEF-P WM scale and the SOPT –WM task were related, suggesting that children who were perceived as having the capacity to hold information in their mind as expected for their age demonstrated higher working memory spans on the SOPT –WM task. A number of possible explanations for these results are considered and include construct validity, ecological validity, and the overlap of processes involved in EF.

**Construct validity.**

One explanation for these results could be attributed to the variability in the how the components of EF are defined for each measure. This was a primary issue addressed in the literature review, which emphasized the inconsistencies with how both the construct of EF and also the components of EF are characterized, delineated, and defined.

**Inhibition**

The Flanker –inhibition task has strong evidence to support its measurement of inhibition as defined by alerting and orienting attention (e.g., Mezzacappa, 2004), and according to Hongwansihkul et al. (2005) would represent the measurement of a “cold” EF component. In contrast, the BRIEF-P inhibit scale has strong evidence to support its
measurement of behavioral regulation (Isquith et al., 2004), and could be considered a “hot” component of EF (Hongwanishkul et al., 2005). As previously stated in the literature review, the term inhibition has been used to describe both the suppression of a prepotent response (and typically somatic, motor response having to do with overt behavior) and the control of attention (having to do with covert behavior) (Niggs, 2000). Other researchers refer to these same processes as response inhibition or conceptual inhibition (e.g., Bialystock & Martin, 2004). Thus, it is important to consider how inhibition is defined within the context of the measurement tool, and it is important to identify the purpose of the measurement tool. Based on this information, the BRIEF-P inhibit scale and the Flanker-inhibition task measure different aspects within the construct of inhibition. However, the convergent validity between the two measures of inhibition may also provide support that the two aspects of inhibition (behavioral regulation and the control of attention) occur simultaneously and are both necessary for goal-directed problem solving. This is important to recognize; for example, when a child inhibits from knocking over a block tower, s/he is suppressing a motor response while also attending to an internal representation of his or her choices. This example could also be argued to involve both shifting and working memory, hence reflecting the variability in which the components of EF are defined, and also adding considerable evidence that EF components are interrelated.

**Shifting**

A similar issue of construct validity is raised in regards to the measurement of shifting and may help to explain some of the findings from this study. The BRIEF-P shift
scale and the DCCS-shift task were not found to have significant convergent validity; however, the DCCS–shift task and the BRIEF-P inhibit scale were significantly correlated. The DCCS–shift task has strong evidence to support its measurement of attention shifting (Frye et al., 1995; Zelazo et al., 2003) and is widely used and accepted as a tool for measuring shifting in young children (Garon et al., 2008). Interestingly, Bialystock and Martin (2004) described the DCCS task (in a slightly different version than the one used in this study) as a measurement of both response and conceptual inhibition, which is contradictory terminology to what the DCCS task purports to measure (Zelazo et al., 2003). Since the two EF components of inhibition and shift are not clearly delineated in the literature and are sometimes used interchangeably, this may be one explanation as to why the inhibition and shift tasks were significantly correlated.

Additional evidence points to the integrated processes of EF (e.g., Garon et al., 2008) suggesting that the correlations among EF measures would be expected (discussed further, below).

The BRIEF-P shift scale also has evidence to support its measurement of attention shifting (similar to the DCCS–shift task), but also includes the measurement of more overt behaviors (which the DCCS task does not), such as the ability to move freely from one situation, routine, or activity to another without becoming upset (Gioia et al., 2004). The difference in how shift is defined for each measure leads to the inconsistency of correlations found in this study. Why the two inhibit scales correlated and the two shift scales did not correlate warrants consideration of inconsistent construct definitions and also the instability of EF measurement in young children.
Working memory

Finally, the SOPT–WM task was correlated with the BRIEF-P WM scale as well as with the other two EF tasks. Essential to the finding that the two working memory measures were related is the recognition that the construct of working memory has been defined in different capacities. For example, the authors of the BRIEF-P define working as the “ability to hold information in mind for the purpose of completing a task or making a response” (Gioia et al., 2003, p 18). Questions on the BRIEF-P related to working memory reference children’s abilities to carry out multistep tasks, implement a sequence of actions, or follow complex instructions (Gioia et al., 2003). To review, many researchers differentiate between visual (or visio/spatial) and verbal working memory (e.g., Baddeley, 1986; Bull et al., 2008). Questions on the BRIEF-P tap primarily verbal working memory whereas the SOPT–WM task demands primarily visual working memory. Dehn (2008) separates working memory processes that are executive in nature and those that are domain specific working memory processes (verbal and visual) and notes that some theorists (e.g., Baddeley, 1986) give the impression that working memory and broad executive processes are the same construct. Dehn (2008) suggests that the failure to distinguish between the broad executive processes and domain-specific working memory processes creates measurement and diagnostic challenges (see Dehn, 2008 for more details). Based on this information, it seems precarious to draw the conclusion that the BRIEF-P WM scale and the SOPT-WM task, although correlated, measure the same aspect of working memory. This reiterates the need for a multi-faceted approach to
assessment and further raises questions about the purpose of assessing working memory in young children.

The relationship found in this study between working memory and inhibition is consistent with previous findings (Espy et al., 2004). In further support of this finding, the inhibition of interferences is suggested to be the central control function of working memory and one of the foundations of working memory capacity (Kane & Engle, 2002). For example, individuals with low working memory spans are more susceptible than those with high spans to interference from long term memory. Bull and Serif (2001) reported that greater interference, as measured by the Stroop task, was related to lower working memory spans in 6- and 7-year-old children. Further, in relation to children with learning difficulties, Hasher and Zacks (1988) reported that the breakdown of inhibitory mechanisms, not only allows irrelevant information to enter working memory, but that it also allows this information to remain active for a longer period of time, thus having a detrimental effect on performance. These previous findings may be true in older children; however, one of the recent developments of understanding EF in young children is that EF processes begin in infancy with simple representation and interact with other EF processes to develop more complex skills (Garon et al., 2008). Garon and colleagues report that working memory is the foundation for the development of inhibition, and infants must be able to hold simple representations in their mind before developing the ability to impose cognitive control over behavior. In summary, there is clear evidence to demonstrate that inhibition and working memory are related and are integral EF processes in both young and older children.
Overlap of EF components

Different patterns of relations were found among the measures of EF. These correlations were found between the BRIEF-P and the performance-based tasks, among the BRIEF-P scales, and among the performance-based tasks. These findings suggest that performance on these tasks relies on common processes and indicates that these components are not necessarily clearly dissociable as some have suggested (e.g., Bull et al., 2008; Diamond, 2006; Espy & Cwik, 2004; Espy, 2004). Garon et al. (2008) summarized that attention-shifting tasks, such as the DCCS, build upon other EF components. In this respect, the development of the ability to perform this type of shifting task is intimately tied to the development of inhibition and working memory. Mazzocco and Kover (2007) reported an overlap in the correlations among the Contingency Naming Tests (which they used as a measure of EF) and suggested that tasks used to measure EF components do not necessarily clearly measure distinct aspects of executive function. As another example of integrated EF components, the authors of the BRIEF-P note that integral to working memory is the ability to sustain attention, and although these have been conceptualized as distinct entities, the authors acknowledge that the behavioral outcomes of these two domains are difficult to distinguish (Gioia et al., 2003). Finally, researchers have questioned the role of attention networks as an integral factor in EF, and is referenced to be interrelated with working memory (e.g., Gioia et al., 2003), inhibition (e.g., Barkley, 1997; Diamond, 1988; Mezzacappa, 2004), and shifting (e.g., Baddeley, 1996; Garon et al., 2008).
In summary, EFs show considerable overlap based on previous research and the outcomes of this study. Thus, two questions are posed and discussed throughout the remainder of the paper: (a) what is the value in assessing these components of EF as distinct processes if there is evidence to support that they are interrelated, and (b) how should assessment results of EF tests with young children be interpreted?

The most reasonable argument for answering the first question may be evidenced by Garon et al. (2008) who concluded that further research is needed in order to ascertain a coherent theory of EF in young children. This perspective stems from cognitive and developmental psychology, and although pertinent to the progression of the field, the question remains as to the functional use of assessing separate EF components. A second reason that some professionals suggest assessing the distinct EF components is for the purposes of leading to identification of disorders with known EF deficits, such as ADHD, learning disabilities, fragile X syndrome, or autism spectrum disorders. However, due to the complexity of the processes that underlie young children’s performance on EF tasks as well as the instability of measurement with EF tasks, clinicians should treat results from EF tests with caution.

From an educational perspective, one proposed suggestion is that for educators working with young children, understanding the concept of EF and how it is integral to learning and development may more be pertinent than the direct assessment of the individual EF components. It would be helpful for educators to know which aspects of EF are most relevant for learning and school readiness at particular developmental periods. Further, for school psychologists or other education professionals, it is relevant
to consider a multi-faceted approach when assessing any aspect of development or learning, and tools, such as the BRIEF-P, could be used in combination with other methods of assessments (observations, portfolios, interviews, play-based, etc) in order to provide information for instructional or intervention planning.

**Ecological validity.**

A final explanation for the resulting EF correlations may be partially attributed to the discrepancies between experimental tasks and naturalistic tasks that are encountered in everyday life. The lack of ecological validity has been a criticism for experimental tasks and traditional neuropsychological tests (Chan, 2008). The authors of the BRIEF-P report that this measure provides a high degree of ecological validity of everyday behavioral manifestations of executive functioning, but lacks the ability to provide process-specific information as found in a clinical assessment, suggesting the need for utilizing two approaches to EF measurement (Isquith et al., 2004). In other words, if a teacher and a parent perceive a child to have difficulty with inhibition skills while in the context of their environment, does this child also display difficulty solving an inhibition task on a performance-based measure? The fact that the EF performance-based tasks lack the measurement of real-world behaviors in the context of the child’s environment may provide some explanation as to why there were inconsistent correlations between the two inhibition measures. Given the hypothesized multifaceted models of EF, no single measure is likely to be adequate in assessing this complex but critical domain. Isquith et al. (2004) advocate for a model of neuropsychological assessment that explicitly incorporates both the specific process components typically defined by laboratory or
performance tests and the more broad real-world behavioral manifestations of the specific processes or components. Together, these provide a method of balancing internal validity and ecological validity in order to guide assessment and the subsequent intervention planning and monitoring. Again, professionals need to be cognizant when interpreting EF test results since performance on EF tasks can be affected by other factors (i.e., type of task) and may show low association with real-life behaviors. This further supports the earlier suggestion that a multi-faceted approach must be utilized when assessing EF.

**Group Differences on Executive Function and Math Measures – Question 2**

The second aim of this study was to examine the effect of age, gender, and dual language experience on young children’s executive functioning and early mathematical skills. As expected, age-related improvements in performance were found for all three measures of EF and on the CMA, consistent with the notion that components of EF develop rapidly during the preschool years (Bull & Scerif, 2001; Carlson, 2005; Espy et al., 1999; Garon et al., 2008; Hughes, 2002; Jacques & Zelazo, 2001; Zelazo & Muller, 2002). In particular, age-related improvements were seen on the Flanker-inhibition task, the SOPT –WM task, and the DCCS –shift task. On the Flanker –inhibition task, 4-year-olds demonstrated greater proficiency than 3-year-olds on measures of speed and accuracy. Consistent with findings from Mezzacappa (2004) and Rueda et al. (2004), older children were less hindered by the interference of competing demands (i.e., the target fish facing the opposite direction) and thus were more efficient and accurate when these demands were present. A similar pattern was identified on the SOPT –WM task, where 4-year-old children demonstrated a greater ability to successfully complete more
trials than 3-year-old children. These results are consistent with previous findings that showed age-related improvements between 3-, 4-, and 5-year-old children in performance on working memory tasks (e.g., Hongwanishkul et al., 2005; Zelazo & Muller, 2002). Finally, 4-year-old children were more likely to complete the post-switch condition than were 3-year-old children, consistent with previous findings using the DCCS –shift task (Bialystock & Martin, 2004; Hongwanishkul et al., 2005; Zelazo et al., 2003; Zelazo & Frye, 2002). These findings are supported for a wide variety of EF tasks that tap into inhibition, working memory, and shifting (Carlson, 2005; Garon et al., 2008).

One implication from these findings is the importance of understanding the developmental progression of EF for assessment and interpretation. For instance, it would be impractical to be concerned about a 3-year old child who failed to switch between two rule sets or was having difficulty playing a game in which two rules were involved simultaneously. If it is typical for a 3-year-old child not to possess the cognitive ability to shift between two rule sets, then why would it be important to assess shifting abilities of a 3-year-old child? This question can be addressed from the two approaches discussed earlier: an educational psychology approach or a cognitive and developmental psychology approach. From an educational perspective, one reason that the assessment of EF at different ages could be beneficial is that it may provide clues as to the nature of the EF impairment in early emerging disorders (Garon et al., 2008), such as autism or attention-deficit hyperactivity disorder. If clear patterns of executive dysfunction exist, earlier identification of these deficits could lead to earlier and more targeted intervention strategies. Consideration of the type of EF assessment (i.e., screening instruments,
diagnostic tests, play-based, curriculum-based) used would be crucial for interpreting
developmental differences and for helping to identify classroom instructional strategies.
Additionally, interpreting assessment results, professionals should be cognizant of the
variation in what is considered developmentally appropriate skill acquisition and what is
considered dysfunctional for a particular age.

From a cognitive and developmental psychology perspective, the assessment of
age-related changes in EF is necessary to further our understanding of how attentional
control and environmental stimulation impact EF development (e.g., Garon et al, 2008).
And as mentioned earlier, developmental researchers purport that assessment of EF in
young children is necessary in order to formalize a unified developmental theory of EF
(e.g., Marchovitch & Zelazo, 2009). Although many studies show progression towards
understanding early development of EF, this remains an area for further research.

Gender.

No gender differences emerged in this sample on the inhibition, working memory,
or CMA measures, but a difference was observed between gender groups on the DCCS –
shift task. In support of the current findings, most research to date indicates that boys and
girls develop EF processes at a similar rate (Anderson, 2002). Some gender differences
have been identified on specific tasks, although these findings have not been consistently
replicated in other studies. Girls aged 3-5 have been reported to outperform boys in the
areas of attentional control and response inhibition (as measured by the subtests on the
NEPSY –II), but performed similar to the boys from age 6-years onward (Klenberg,
Korkman, & Lahti-Nuuttila, 2001). An effect of gender was found on set-shifting tasks,
after controlling for age, IQ, and other EF components for children aged 8 and older (Kalkut, Duke, Lansing, Holdnack, & Delis, 2009). Other researchers have examined gender differences in EF in clinical samples and have found some evidence towards a stronger relation between executive functioning and ADHD symptoms for boys compared with girls (Berlin, Bohlin, & Rydell, 2003). Raaijmakers et al. (2008) reported gender differences with preschool children in inhibition, verbal fluency, working memory and set shifting irrespective of aggression or attention problems. Finally, the authors of the BRIEF-P report that in the parent sample, small differences emerged between boys and girls on the Inhibit scale, with boys rated as having somewhat poorer inhibitory control than girls. In the teacher sample, boys similarly were rated as having greater inhibitory difficulties than girls, and were rated as having poorer WM (Gioia et al., 2003).

In summary, some differences between genders have been reported in the literature, but it is inconsistent, and more research is needed in this area in order to draw further conclusions.

Although there are inconsistencies in the literature regarding gender differences in executive functioning abilities, as a result, future studies should analyze girls and boys separately. There are implications for the standardization of EF assessments, particularly for the NIH Toolbox which is currently in the norming process. The BRIEF-P (Gioia et al., 2003) does provide separate norms for girls and boys, and this appears to be an important practice when interpreting assessment results.
Language groups.

The current findings replicate and extend previous research on differences between language groups on EF performance. Again, this discussion draws upon previous research that uses the term bilingual, due to limited research that uses the term DLLs. Consistent with Bialystock (1999) and Carlson and Meltzoff (2008), children in the DLL group performed significantly better on the Flanker –inhibition task and on the DCCS –shift task than English speaking children both before and after accounting for vocabulary differences. Bialystock and Martin (2004) found similar evidence for a clear bilingual advantage for both inhibition and attentional control on the DCCS task and concluded that this was not due to a superior ability to represent complex stimuli, but rather the advantage attributed to greater conceptual inhibition. This suggests that the children who were DLLs were able to decode/encode the information more efficiently. In the DCCS post-switch phase, children deal with a conflict of two rule sets, thus they are required to inhibit a previously learned rule in order to successfully sort where the correct card goes. The theoretical implication is that the pattern of findings suggests a specific role for inhibition and shifting in the link between bilingualism and EF. However, the issue of EF measurement and construct definitions is essential to understanding these findings. The inhibition task used in this study measured a child’s ability to attend and to inhibit a visual representation (where there is a bilingual advantage) versus the inhibition of an action/motor response, in which there has not been support for a bilingual advantage (Carlson & Meltzoff, 2008). These finding have implications for the assessment of children who are DLLs. Considering that inhibition and shifting impact
learning (e.g., Bull et al., 2008; St. Claire Thompson & Gathercole, 2006) and that there are evidenced differences on these EF components between bilingual/DLL populations and monolingual English speaking children (e.g., Bialystock, 1999; Bialystock & Martin, 2004), then we cannot validly compare children between groups or make placement decisions based on assessments that were normed for one group or the other. Thus, the fairness and the validity of assessment tools are essential issues to consider.

No language group differences emerged for performance on the CMA despite the evidence that the groups differed on vocabulary ability. One explanation for these results is that the children from this sample were from low SES homes (as a requirement for entry into Head Start programs), which according to Starkey et al., (2004) contributes to a less extensive mathematical knowledge compared to peers from higher SES families despite language differences. Thus, for children in this sample, the low SES factor was more relevant than whether they were a dual language learner when accounting for mathematical knowledge. This has substantial implications for considering classroom instruction for children from low SES families because children from this population may acquire mathematical knowledge at a similar rate despite language differences. As mentioned earlier, Starkey et al. (2004) suggest that early childhood programs serving low-income families must integrate time- and place-specific curriculums in order to support the development of mathematical knowledge.

**Executive Function as a Predictor of Early Mathematics –Question 3**

Executive functions were related to early mathematical abilities in preschool children. Both working memory, and to a lesser extent, inhibition, contributed to early
mathematical performance in this age group. These findings support previous research with this age group and further support the developmental link to similar relations between EF and mathematical performance previously reported in school-age children (e.g., Bull & Scerif, 2001; McLean & Hitch, 1999; St. Clair-Thompson & Gathercole, 2006).

The contributions of working memory and inhibition to early mathematical skills were significant, while the contribution of shifting was not. The relation of working memory to mathematics was large, even after statistically controlling for the effects of age and vocabulary ability. Furthermore, working memory predicted early mathematical skills in preschool children when the influences of inhibition and shifting were controlled. Working memory still accounted for 7% of mathematical skill variability, whereas inhibition accounted for only 4% of the variability after controlling for working memory and shifting. In contrast, Espy et al. (2004) found that in preschool children, working memory (assessed by three tasks) accounted for only 3% (small significance) and inhibition accounted for 12% of the unique variance in mathematical performance after controlling for child age, vocabulary ability, and maternal education level. These relative differences in magnitude of the effect of working memory and inhibition are particularly salient, as in both studies, the predictive models accounted for a comparable overall percentage of mathematical performance variability ($R^2 = 61\%$ in this model, $R^2 = 52\%$ in Espy et al., 2004). Similar accounts have been identified with school-aged children, suggesting that contribution of executive functioning abilities to mathematical skills begins in early childhood and continues through grade school. Gathercole and
Pickering (2006) found that both working memory and inhibitory skills were significantly associated with educational attainment, and similar to this study, the magnitude of the associations between achievement (in both literacy and math) and working memory was considerably higher than the links found between achievement and inhibitory skills.

**Working memory and early mathematical knowledge.**

The findings that working memory predicted early mathematical skills have been reported by a number of authors (e.g., Gathercole et al., 2004; Kytta et al., 2010) who have distinguished between verbal working memory and visuo-spatial working memory (VSWM). Recently, Kytta et al. (2010) found that after controlling for age, the correlations between VSWM and early mathematical skills diminished, suggesting that most of the relationships between VSWM and early mathematical skills can be explained by the variation in age and indicates a normal developmental pattern. However, the capacity to temporarily store sequentially presented visuo-spatial information correlated highly with early mathematical skills (.66) in the control group (the experimental group being those children identified with a mathematical difficulty). Stronger associations between VSWM and mathematics achievement in school-aged children was reported by Gathercole and Pickering (2006), whom suggest that VSWM may have more pervasive links to mathematics than verbal working memory.

Consideration that working memory had the strongest influence on early mathematical performance beyond the other two EF components may have some implications for preschool educational practices. As previously mentioned, the SOPT–WM task can be categorized as assessing VSWM versus verbal working memory, as
differentiated by Baddeley (1986) and Welsh (2002). Perhaps visual/spatial materials could be used more extensively and creatively when fostering early mathematical skills, especially considering the CMA results that showed children performed very poorly in the domain of patterning/logical relations. The National Council of Mathematics Teaching (2000) lists several expectations relating to young children’s understanding and application of spatial relationships as one of the foundations of early geometry. Games that promote mathematical thinking through visual representations could also be integrated throughout a daily curriculum. Recently, Siegler and Ramani (2009) found that children from low-income families who played linear board games (e.g., similar to ‘Chutes and Ladders’) demonstrated an increased understanding of numerical magnitudes compared to children who played circular board games and children in the control condition. The authors suggest that numerical knowledge increases when children are able to develop linear visual representations. Additionally, they found that the greater amount of experience that children had playing board games in their home environments, the more proficient the children were at number line estimation, numerical magnitude comparison, counting, and numeral recognition (Ramani & Siegler; 2008). Visual representations were key elements to the two aforementioned studies, thus further supporting the evidence that VSWM plays an integral role in the development of mathematical knowledge. Given this information, it is essential to incorporate visual-spatial materials, activities, and games into an early childhood curriculum.

A number of curriculums for improving low-income preschoolers’ mathematical knowledge have shown large positive effects. Pre-K Mathematics improved pre-
kindergarteners mathematical knowledge at the end of the program to be equivalent to that of middle income peers who did not participate in the curriculum (Starkey et al., 2004). Similarly, the Building Blocks curriculum (Clements & Sarama, 2007) led to preschoolers from low-income backgrounds making much greater progress than the control group in number, geometry, numerical knowledge, measurement, and recognition of patterns. These curriculums include a variety of components, thus making it difficult to identify which activities had the greatest impact on mathematical knowledge. Nevertheless, positive outcomes were found, which suggests that curricula can have a direct positive impact on low-income children’s mathematical knowledge. In summary, it is clear that working memory, and specifically VSWM, plays an integral role in the development of early mathematical skills and that early childhood curriculums have the potential to promote these skills in classrooms serving low-income families.

**Influence of language on early math.**

Of pertinent interest was the finding that children’s vocabulary scores accounted for 20% of the variance in early mathematical skills after controlling for age and previous Head Start experience. This was a greater contribution to early mathematical skills than any of the EF scores. Bialystock (1999) suggested that the frontal cortex is not only involved in shaping language, but also that, in turn, language experiences can influence further development of frontal lobe functions such as inhibition and the control of attention. Bialystock and Martin (2004) concluded that early childhood bilingualism modifies children’s control of attention, providing support for the interplay between language and EF. Similarly, Carlson and Meltzoff (2008) proposed that early exposure to
more than one language may foster the inhibition and working memory skills necessary for cognitive flexibility in a variety of problem-solving situations. Following the evidence summarized in this study and previous authors’ theories regarding the dual direction of influence between language and EF, it is proposed that this idea may be particularly salient in a low SES and DLL population, where language abilities may play a stronger role in skill acquisition than do executive functions.

**Promoting Executive Functions in Prekindergarten**

The finding that EF skills, namely working memory and inhibition, were related to early mathematical skills suggests that children might benefit if prekindergarten programs also made concerted efforts to promote the development of working memory and inhibitory control. Welsh, Nix, Blair, Bierman, and Nelson (2010) suggest that attentional control is important to promote within prekindergarten programs, which as previously stated, is a term that has also been used interchangeably with inhibitory control (e.g., Espy & Bull, 2005). The challenge is that, at present, much less is known about how preschool programs can promote these kinds of skills than is known about the scope and sequence of emergent literacy and math skill instruction (although this is also limited).

One approach to the promotion of working memory and inhibition skills involves providing children with repeated practice sessions on specific EF tasks (Klingberg, Forssberg, & Westerberg, 2002; Rueda et al., 2005). This cognitive training approach has primarily been utilized with older children and within laboratory settings (e.g., Klingberg et al., 2002), thus whether these types of activities are appropriate for preschool children
or whether they will promote generalized learning gains in the classroom remain unclear. Positive academic gains have been demonstrated with preschool children using computer-assisted instruction (CAI) that target academic skills (Clements, 2002; Clements & Nastasi, 1993), yet Welsh et al. (2010) note that no studies have yet demonstrated the benefits of computer-based training of specific EF skills for preschool children or linked these improvements to changes in academic skills.

Another approach to supporting the development of EF utilizes preventative intervention programs and social-emotional skill training programs. Although very few programs intend to explicitly promote the development of children’s EF abilities, some promote skills that may ultimately aid in the development of children’s EF by targeting the enhancement of competencies and skills considered to be in the domain of EF. Examples of such programs include I Can Problem Solve (ICPS; Shure, 2001), Second Step (Fitzgerald & Edstrom, 2006), Tools of the Mind (Bodrova & Leong, 1996), and Promoting Alternative Thinking Strategies (PATHS; Greenberg & Kusche, 2006), each of which target aspects of emotional regulation, self-control, and social problem solving. Some recent intervention trials have shown improvement on learning and on EF tasks using psychosocial intervention programs (e.g., Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008). For example, in a Head Start REDI project, the Preschool PATHS intervention programs had significant effects on children’s performance on the DCCS task. This program is designed to enhance areas of social-emotional development using direct instruction, discussion, modeling, storytelling, role-playing activities, and video presentations (Greenberg & Kusche, 2006). Interestingly, the intervention appeared
particularly beneficial to children who started the year with low levels of behavioral inhibitory control (e.g., difficulty with delaying motor responses and sustaining attention) (Bierman et al., 2008). Consistent with this finding, some research linking EF abilities to aspects of behavioral control implies that children with deficient EF abilities may begin an intervention with less abilities to inhibit impulsive behaviors, problem solve, and attend than children with EF proficiencies (Hughes, 2002; Stuss & Benson, 1984). These types of intervention programs and curricula provide a promising outlook on helping to promote EF in young children.

Finally, best practices in early childhood education should support the development of EF, without isolating or targeting specific EF skills. For example, teachers who facilitate problem-solving and reasoning skills, such as helping children think independently, asking questions about new ways to solve a problem, or proposing alternative strategies, are supporting EF development through an integrative approach. Teachers who encourage recalling stories or events, help children learn to visualize and represent objects, or encourage children to imitate and model behaviors are supporting the development of memory. These skills can be enhanced by environments that support curiosity and risk-taking, both of which facilitate divergent thinking skills. Essentially, the development of executive functions can easily be promoted through good teaching techniques and best practices in early childhood education.

Limitations

This study had several limitations that must be considered when interpreting the data. One important limitation was the limited number of tasks used to assess inhibition,
shifting, and working memory. The NIH Toolbox (Gershon & Zelazo, 2009) is designed to provide a measurement of EF in young children; however, only one task comprises the measurement of each EF component. Most past research on EF skills in preschool children has used a combination of tasks to create a composite measure (e.g., Espy & Bull, 2005; Hughes & Ensor, 2007; Weibe et al., 2008). A multiple task approach may be a more effective approach than using only one task, given that tasks measuring EF vary in the stimulus content (verbal vs. nonverbal), response type (motor vs. naming), inhibitory demands (attention control vs. response suppression), and type of conflict (proactive interference vs. distraction) (Espy & Bull, 2005). However, developmental research has indicated that these tasks used in the NIH Toolbox (DCCS, Flanker, Self-Ordered Pointing task) are sensitive to the rapid growth in these EF skills that occur during the preschool period (Blair et al., 2005; Rueda et al., 2005; Zelazo & Frye, 2002). A

Further, the tasks that comprise this measurement tool require a high level of language comprehension. Although no verbal responses are required, children must comprehend complex directions (e.g., “touch the arrow that faces the same way the middle fish is facing”), concepts, and vocabulary (e.g., “middle”). Although a number of practice trials are completed, it is possible that some responses are correct due to guessing. This study sheds light on the important conceptual and measurement issues regarding EFs in young children, and the findings suggest that these cognitive skills deserve further research and greater attention in preschool curricula, given the evidence of the important role they play in children’s learning.
Second, the Child Math Assessment also has measurement limitations. Although the standard version of the CMA demonstrates strong reliability and validity (Starkey et al., 2004) the shortened version used in this study does not have the research to demonstrate content validity. As previously mentioned, the numbers of tasks that make up each domain vary, with the patterning and logical relations domain containing the least number of tasks. Additionally, the CMA has some directions that are complex. For example, “point to the side of your triangle that is the same as this side, then put this piece on that side of your triangle.” However, a critical benefit of the CMA is that it measures an array of early mathematical domains, as compared to many other early math assessments which focus primarily on numeracy and arithmetic domains.

A third limitation that is important to note is that two different receptive vocabulary tests were used (the PPVT-4 and the TVIP) and the standard scores were treated equally. Although the TVIP demonstrates strong correlation with the PPVT-R version, no studies have correlated it with the PPVT-4, and thus the concurrent validity is not known.

Fourth, given the measurement limitations of the study, the researcher relied on multivariate analysis of variance and regression analyses to examine developmental processes. Due to these statistical methods, a model of EF could not be proposed; whereas conducting structural equations models would provide more rigorous methodological analyses for examining a model of EF. Welsh et al. (2010) suggest that it may be difficult to estimate latent constructs necessary for these types of methodologies because of measurement challenges in assessing multiple dimensions of EF in young
children. Additionally, the lack of differentiation that actually exists in some aspects of EF in young children also proposes challenges to estimating latent constructs (Welsh et al., 2010).

Finally, the design of the study precludes any firm conclusions about causal effects. Due to the exploratory nature of this study, only the relationships that exist between the EF measures, the differences between groups in this study (age, gender, language), and that domain-specific EF skills and vocabulary knowledge are related to early mathematical knowledge can be specified. This study is not able to suggest that executive functioning abilities of young children cause certain educational outcomes, nor preclude that vocabulary abilities have an effect on the development of EF or early mathematical knowledge. Experimental evidence would be necessary to make claims about causation of EF to learning.

**Summary and Future Research**

This study supports and extends the literature on several accounts. Preliminary analyses revealed pertinent information related to the research questions of interest. First, DLLs were found to have lower receptive vocabulary knowledge as compared to their monolingual English speaking peers from a similar low SES background. This information is pertinent to consider for assessment practices because children’s response to curriculum, intervention, or instructional strategies can vary based on their language proficiency and thus comparison to peers with different language proficiencies may provide invalid data. As the term DLL becomes used more frequently, there needs to be a
clearer delineation between what constitutes a Dual Language Learner versus an English Language Learner versus someone who is bilingual.

Second, preliminary analyses also revealed that children with IEPs did not differ from those without IEPs on the measures of receptive vocabulary knowledge, EF abilities, or mathematical skills. The sample of children with IEPs was small, and thus it would be interesting to investigate these comparisons with a larger sample and with children from a variety of SES backgrounds. And third, results from the CMA proved that children in this Head Start sample lacked knowledge in the areas of early numeracy and patterning/logical relations as compared to the other two domains of arithmetic and geometry/spatial reasoning. Future research may want to examine children’s mathematical knowledge from a qualitative approach in order to better understand the process in which children solve problems. For example, observational data from the CMA could provide valuable information about children’s problem-solving processes and the patterns in which they complete the tasks. Overall, it is apparent that more work is needed to identify optimal instructional strategies and early childhood curricula that will target the development of early mathematical knowledge, particularly for programs serving families from low SES background. Although some researchers (e.g., Clements & Sarama, 2007; Klein & Starkey, 2004) have shown positive outcomes from mathematics intervention outcome studies, there remains a gap between the research and the implementation of these programs and the professional development resources to support program sustainability.
Significant relations were found between the rating scale measure of EF and the performance-based EF tasks. Convergent validity between the BRIEF-P scales and the NIH Toolbox was inconsistent, with significant overlap among the EF tasks. Performance on these tasks relies on common cognitive processes, suggesting that executive functions are not clearly dissociable (e.g., Garon et al., 2008; Mazzocco & Kover, 2007). Age-related differences on the EF tasks were found, supporting the evidence that EF processes are undergoing development during the preschool period. Further, differences between dual language learners and monolingual English speaking children were found on the EF measures of inhibition and shifting. It is important to identify that the tasks used to measure inhibition and shifting both required a nonverbal response, a low demand of working memory, and a prepotent/distracting response. These findings are consistent with previous research (e.g., Carlson & Meltzoff, 2008), and offer insightful information about the cognitive processes that occur during the preschool period and of which are essential for language acquisition. These findings offer important implications for assessment practices and young children. Professionals need to be cognizant when interpreting EF test results because for example, performance on EF tasks can be affected by other factors (i.e., type of task) and may show low association with real-life behaviors. Rating scale tools, such as the BRIEF-P, should be used in combination with other methods of assessments (observations, portfolios, interviews, play-based, etc) in order to provide information for instructional or intervention planning. Finally, language exposure plays a vital role in children’s development. Issues including the validity and fairness of
assessment tools and the interpretation of results for DLLs are integral to educational practices.

Finally, this study adds to existing evidence that the executive functions of working memory and inhibition contribute to children’s early mathematical knowledge, as well as children’s vocabulary knowledge. However, this study extends previous research by demonstrating the existence of these relationships with a population of dual language learners from low SES backgrounds. Working memory accounted for more variance than did inhibition in children’s math performance, and vocabulary scores accounted for the largest variance. The dual-directional influence of EF and language on children’s early learning can be considered an important factor when doing future research with both low SES populations and dual language learners. Further, promoting EF in early childhood classrooms may provide benefits for learning and school readiness. However, it is clear that more research is needed in order to identify the optimal strategies for enriching preschool programs in ways that will foster growth in EF, and at which points in development interventions targeting executive functions are most likely to be helpful in promoting academic growth.
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Appendix

Child Math Assessment

1. Object Counting (Counting Strips)

Stop Rule: If child is incorrect on 2 consecutive items, end task.

Materials: Linear arrays of items (3, 7, 10, 15, 30) glued to poster board.

Prompt: If child fails to report cardinal value spontaneously, prompt by asking, “How many are there?”

Instructions: Record the cardinal value given by the child and any counting errors made.

Scoring: If the child gives the correct cardinal value and did not make any counting errors, score as “Correct.” If the cardinal value is incorrect and/or the child made any counting errors, score as “Incorrect.” If the child answers by showing their fingers, ask, “How many is that?” Record the child’s verbal response. If the child gives a verbal and finger response, record the verbal response only.

Types of Counting Errors:

Tagging: Violating one-to-one correspondence (skipping/double counting items)

Number Series: Reciting number words in the incorrect order (e.g., “1, 3, 4”). Also includes invented number words (e.g., “eleventeen,”).

Cardinality: Failure to understand that the last number counted represents the total number of objects in the set (e.g., “1, 2, 3, there are 5”). Also includes recounting when prompted, “How many are there?” (e.g., Child counts “1, 2, 3.” E prompts, “How many are there?” Child counts “1, 2, 3” again).

Script:

“Count these (object names) and tell me how many there are.”

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 (3)</td>
<td>1.2 (7)</td>
<td>1.3 (10)</td>
<td>1.4 (15)</td>
</tr>
<tr>
<td>☐ Correct</td>
<td>☐ Correct</td>
<td>☐ Correct</td>
<td>☐ Correct</td>
</tr>
<tr>
<td>☐ Incorrect</td>
<td>☐ Incorrect</td>
<td>☐ Incorrect</td>
<td>☐ Incorrect</td>
</tr>
</tbody>
</table>

Type of Error:

Tagging | Tagging | Tagging | Tagging | Tagging
# Series | # Series | # Series | # Series | # Series
Cardinality | Cardinality | Cardinality | Cardinality | Cardinality

Materials:
Linear arrays of items (3, 7, 10, 15, 30) glued to poster board.

Prompt:
If child fails to report cardinal value spontaneously, prompt by asking, “How many are there?”

Instructions:
Record the cardinal value given by the child and any counting errors made.

Scoring:
If the child gives the correct cardinal value and did not make any counting errors, score as “Correct.” If the cardinal value is incorrect and/or the child made any counting errors, score as “Incorrect.” If the child answers by showing their fingers, ask, “How many is that?” Record the child’s verbal response. If the child gives a verbal and finger response, record the verbal response only.

Types of Counting Errors:

Tagging: Violating one-to-one correspondence (skipping/double counting items)

Number Series: Reciting number words in the incorrect order (e.g., “1, 3, 4”). Also includes invented number words (e.g., “eleventeen,”).

Cardinality: Failure to understand that the last number counted represents the total number of objects in the set (e.g., “1, 2, 3, there are 5”). Also includes recounting when prompted, “How many are there?” (e.g., Child counts “1, 2, 3.” E prompts, “How many are there?” Child counts “1, 2, 3” again).
2. One-set Addition and Subtraction, Objects Hidden (Fish Game)

<table>
<thead>
<tr>
<th>Stop Rule</th>
<th>None. ADMINISTER ALL ITEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>Opaque cup with cover, source set of 8 fish</td>
</tr>
<tr>
<td>Prompt</td>
<td>Between Problems 2.2 and 2.3 say, “Now we are going to play with the fish in a new way.”</td>
</tr>
<tr>
<td>Scoring</td>
<td>Record the answer that child gives and score child's the answer as correct or incorrect for each problem.</td>
</tr>
</tbody>
</table>

(Show empty fish bowl before starting game and after each problem.)

<table>
<thead>
<tr>
<th>2.1 (2+1)</th>
<th>2.2 (3+2)</th>
<th>2.3 (3-1)</th>
<th>2.4 (5-2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>□ Correct</td>
<td>□ Correct</td>
<td>□ Correct</td>
<td>□ Correct</td>
</tr>
<tr>
<td>□ Incorrect</td>
<td>□ Incorrect</td>
<td>□ Incorrect</td>
<td>□ Incorrect</td>
</tr>
</tbody>
</table>
3. Geometric Reasoning (Triangle Game)

**Stop Rule:** On problem 1, if child fails to touch 2 out of 3 SIDES of the triangle – but NOT NECESSARILY the correct sides – end task and do not administer 3.2 and 3.3.

**Training Rule:** If training is given and the child still does not touch his/her triangle, end task.

**Materials:** Two identical small, equilateral triangles, three triangle boards, three sets of colored plastic strips

**Prompt:** “I can’t really see where you are pointing.” (Only give once)

**Scoring:** Record the corresponding sides of child’s triangle for each problem (from the shortest to middle-size to longest).

---

**Script:**

**Warm-up (this task is done only once and is not scored)**

“This is your triangle (point) and this is my triangle (point). Look, when I put your triangle on top of my triangle they make the same shape. So these triangles are just the same. Now we are going to play a game with some other triangles that are the same.”

**All trials**

“Look at these triangles. These triangles are just the same. This is your triangle (point), and this is my triangle (point).”

“Watch what I am going to do. I’m going to decorate my triangle like this.” (Place plastic strips on your triangle starting from side closet to the bottom, then clockwise.)

“I want you to decorate your triangle so it is exactly the same as my triangle now.”

“Touch the side of your triangle that is the same as this side. (Pause and watch the child)

“Now put the colored strip on that side of your triangle.” (Start with the shortest side, middle, then longest)

(If child does not touch anything, or touches your triangle on problem 1, proceed with Training for Problem 1 ONLY)
**Training**

“**This is your triangle (point)** and this is my triangle (point). Touch the side of your triangle that is the same as this side.

<table>
<thead>
<tr>
<th>E’s Triangle</th>
<th>C’s Triangle</th>
<th>Short</th>
<th>Mid</th>
<th>Long</th>
<th>NA</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="slide1.png" alt="Diagram" /></td>
<td><img src="slide2.png" alt="Diagram" /></td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td><img src="rotation1.png" alt="Diagram" /></td>
<td><img src="rotation2.png" alt="Diagram" /></td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td><img src="flip1.png" alt="Diagram" /></td>
<td><img src="flip2.png" alt="Diagram" /></td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>
4. Construction of Equivalent Sets (Ducks, and Bears Strips)

**Stop Rule:** None. ADMINISTER ALL ITEMS

**Materials:** Corresponding models and source sets (7 ducks, 12 bears) for each problem

**Scoring:** Record the number of objects taken out and also score the child’s answer as correct or incorrect for each problem.

_A Script:_

“We are going to play a game with these (ducks/teddy bears). Here are some ([color 1] ducks/[color 2] teddy bears).” (Point to objects affixed to the board). “…and here are some ([color 2] ducks/[color 2] teddy bears). (Show basket with source set of ducks/teddy bears.)

“Go to the bowl and take out the same number of ([color 2] ducks/[color 2] teddy bears) (from the source set) as there are ([color 1] ducks/[color 2] teddy bears).” (on the model set board) (Place container of source set items on the table to the right of the model from the child’s perspective.)

4.1 (3 Ducks) _____ 4.2 (7 Teddy Bears) _____

☐ Correct ☐ Incorrect  ☐ Correct ☐ Incorrect
5. Two-set Addition and Subtraction (Marble Game)

**Stop Rule:** If the child makes an error on the Initial set of a problem, do not perform the addition/subtraction transformation, score the final set as incorrect, and end that problem.

**Materials:** Two opaque containers, cup containing 15 marbles

**Instructions:** Record the child’s judgments (Same, More, or Other). Also, record which container that child says has more. If the child says “yes” or “no” to the two-part question, then examiner should ask each question (same number and more) separately.

**Scoring:** Either child passes or fails for the initial sets and final sets for each problem separately.

---

**Script:**

*Optional:* This is a watching game. I want you to watch closely with your eyes.

**Initial set:**

“Watch as I put some marbles in these containers. I take a marble in this hand and a marble in this hand, and then I drop the marbles into containers at the same time. Now I’m dropping one in here and one in here, and one in here, and one in here, and one in here.”

For problems 5.3 and 5.4, also say “Now I’m dropping another one in here and another one in here.”

“Do the containers have the same number of marbles or does one container have more?”

**Transformation**

“Now I’m (dropping another one in here/taking one from here)”

“Do the containers have the same number of marbles or does one container have more?”

---

**5.1 Initial Set (4 red, 4 blue)**

(+1 blue) transformation

<table>
<thead>
<tr>
<th>Final Set (4 red, 5 blue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
</tr>
</tbody>
</table>

---

**5.2 Initial Set (4 red, 4 blue)**

(-1 blue) transformation

<table>
<thead>
<tr>
<th>Final Set (4 red, 3 blue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
</tr>
</tbody>
</table>

---

**5.3 Initial (6 red, 4 blue)**

(+1 blue) transformation

<table>
<thead>
<tr>
<th>Final Set (6 red, 5 blue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
</tr>
</tbody>
</table>

---

**5.4 Initial Set (4 red, 6 blue)**

(-1 blue) transformation

<table>
<thead>
<tr>
<th>Final Set (4 red, 5 blue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
</tr>
</tbody>
</table>
6. Direct Measurement (Sparky’s Mat)

**Stop Rule:** None. ADMINISTER ALL ITEMS

**Materials:** Toy dog, 6 pairs of similar objects (each pair differs in size/length or weight), 1 mat, 1 tray

**Note:** Order of objects listed on score sheet corresponds with the side the item should be placed from the examiner’s perspective

**Instructions:** Record child’s selection for each problem (record “Both” if child places two objects on the tray).

*Script:*  
“This is Sparky. He wants to play a game with you. This is Sparky’s tray (point). I’m going to show you some things and you get to put the things that Sparky wants on his tray.”

*Item administration*  
“Here are some (dog treats/dog food etc.). Sparky wants the (dog treats/dog food, etc.) that is (heavier/bigger/longer). Can you put the (dog treats/dog food, etc.) that is (heavier/bigger, longer) on Sparky’s tray?”

| 6.1 (Dog Treats) | Child’s Choice: □ Lighter □ Heavier □ Both |
| Manipulates Both Objects: □ Yes □ No |
| 6.2 (Dog Food) | Child’s Choice: □ Heavier □ Lighter □ Both |
| Manipulates Both Objects: □ Yes □ No |
| 6.3 (Water Bowls): | Child’s Choice: □ Bigger □ Smaller □ Both |
| 6.4 (Food Dishes): | Child’s Choice: □ Smaller □ Bigger □ Both |
| 6.5 (Bones): | Child’s Choice: □ Shorter □ Longer □ Both |
| 6.6 (Dog Collars): | Child’s Choice: □ Longer □ Shorter □ Both |

**E’s Left** | **E’s Right**

---

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7. **Shape Recognition (Shape Mats)**

*Stop Rule:* If child uses an incorrect, exhaustive pointing strategy, (i.e. pointing to all the shapes on the board) on two consecutive problems, then end task.

**Materials:** Four laminated shape boards, an erasable marking pen

**Instructions:** Put a dot on each shape that child selects. If child begins pointing and *naming* shapes other than the ones designated, tell child, **"Remember, I want you to point to only the (shapes)."** If the child stops pointing to the circle and looks up as if social referencing, ask, **"Are you done pointing to only the circles?"**

**Scoring:** Score the child’s response (Record “Pass” if child selects all of the correct shapes).

---

**Script:**

“Now we are going to play a game with shapes.”

**Item administration:**

(Hold board against chest with shape side facing against chest) **"In this game I want you to point to the (shapes). I’m going to put a dot on each (shape) that you point to."**

“Remember, point only to the (shapes) and tell me when you are done pointing to the (shapes).” (Place board on table in front of child.)

---

<table>
<thead>
<tr>
<th>7.1: Circle (Top)</th>
<th>7.2: Rectangle (Top)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="circle.png" alt="Circle" /></td>
<td><img src="rectangle.png" alt="Rectangle" /></td>
</tr>
</tbody>
</table>

- □ Pass
- □ Fail

<table>
<thead>
<tr>
<th>7.3: Triangle (Top)</th>
<th>7.4: Square (Top)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="triangle.png" alt="Triangle" /></td>
<td><img src="square.png" alt="Square" /></td>
</tr>
</tbody>
</table>

- □ Pass
- □ Fail
8. Pattern Duplication with Varying Source Sets

**Stop Rule:** If child is incorrect on two consecutive problems, end task.

**Materials:** 4 pre-constructed model patterns, 2 source sets of blocks that are the same color as the model patterns (Problems 1 and 2), 2 source sets of objects (stars and hearts) that differ in color and shape from the model patterns, shallow containers to hold source sets of blocks, and 1 cardboard screen used to conceal model pattern unit.

**Prompt:** If child begins to construct the pattern unit in a vertical orientation or on E’s side of the table, say, “Make the same pattern here” while gesturing to the area in front of the child.

**Scoring:** Score as “Same” if child makes the same pattern, otherwise record “Not Same.” Specify the child’s pattern. If child continues constructing pattern in a vertical orientation after the prompt, score as “Not Same.”

---

**Script:**

Optional: “For this game, this is your side (point) and this is my side (point).”

(Remove screen) “Look at these colored blocks (point to each block individually from child’s left to right). I made a pattern with these blocks.”

Problems 1 & 2:

(Place source set to child’s right) “Use some of these blocks to make the same pattern here” (slide finger in a line along the table in front of the child from child’s left to right).

Problems 3 & 4:

(Place source set to child’s right) “Use some of these shapes to make the same kind of pattern here” (slide finger in a line along the table in front of the child from child’s left to right).

---

**Model Pattern and Correct Response**

**Specify child’s pattern:**

<table>
<thead>
<tr>
<th>Problem</th>
<th>Pattern</th>
<th>Same</th>
<th>Not Same</th>
<th>Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1: R - W - R - W</td>
<td>□</td>
<td>□</td>
<td>(<em><strong>-</strong>__-</em>_<strong>-</strong>__)</td>
<td>R-W-R-W</td>
</tr>
<tr>
<td>8.3: P - W - P - W</td>
<td>□</td>
<td>□</td>
<td>(<strong><strong>-</strong></strong>-____)</td>
<td>S-H-S-H or H-S-H-S</td>
</tr>
</tbody>
</table>

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Stop Rule: If child is incorrect on two consecutive problems, end task.

Materials: 4 pre-constructed model patterns, 2 source sets of blocks that are the same color as the model patterns (Problems 1 and 2), 2 source sets of objects (stars and hearts) that differ in color and shape from the model patterns, shallow containers to hold source sets of blocks, and 1 cardboard screen used to conceal model pattern unit.

Prompt: If child begins to construct the pattern unit in a vertical orientation or on E’s side of the table, say, “Make the same pattern here” while gesturing to the area in front of the child.

Scoring: Score as “Same” if child makes the same pattern, otherwise record “Not Same.” Specify the child’s pattern. If child continues constructing pattern in a vertical orientation after the prompt, score as “Not Same.”
9. Division (Party Game)

**Script:**

**Problem 1:**

(Place two ducks on table in front of child and a plate in front of each duck) **“Look, here are two friends. They are at a party. And here are some toy pigs.”** (show child source set)

“Now can you share these toy pigs (gesture over source set) between the friends (point to each duck) and make sure that each friend gets the same number of toy pigs?” (place source set in front of child)

**Problem 2:**

(Place a third duck and plate on table in front of child and say,) **“Look, another friend is coming to the party. Now there are three friends. And here are some toy clowns.”** (show child source set)

“Can you share these toy clowns (gesture over source set) among the friends (point to each duck) and make sure each friend gets the same number of toy clowns? (place source set in front of child).

**Problem 3:**

(Remove one duck and plate) **“Look, this friend is going home, so now there are two friends at the party. And here are some (fruit).”** (show child source set)

“Can you share these (fruit) (gesture over source set) between the friends (point to each duck) and make sure that each friend gets the same number of (fruit)?”

9.1 Toy Pigs (8 objects / 2 divisors)

<table>
<thead>
<tr>
<th># Friend A</th>
<th>#Friend B</th>
<th>□ Pass  □ Fail</th>
</tr>
</thead>
</table>

Use of temporal one-to-one correspondence: □ Yes □ No

9.2 Toy Clowns (9 objects / 3 divisors)

<table>
<thead>
<tr>
<th># Friend A</th>
<th>#Friend B</th>
<th>#Friend C</th>
<th>□ Pass  □ Fail</th>
</tr>
</thead>
</table>

Use of temporal one-to-one correspondence: □ Yes □ No

9.3 Fruit (11 objects / 2 divisors)

<table>
<thead>
<tr>
<th># Friend A</th>
<th>#Friend B</th>
<th>□ Pass  □ Fail</th>
</tr>
</thead>
</table>

Use of temporal one-to-one correspondence: □ Yes □ No