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Comparing the Predictive Power of Executive Function Assessment Strategies on Preschool Mathematics Performance

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COMPARING THE PREDICTIVE POWER OF EXECUTIVE FUNCTION

ASSESSMENT STRATEGIES ON PRESCHOOL

MATHEMATICS PERFORMANCE

by

Jacob A. Esplin

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ABSTRACT

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Mathematics Performance

by

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Utah State University, 2018

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A child's executive function (aspects: working memory, response inhibition, and set-shifting between sets of rules) capabilities have been found to strongly relate to their mathematics skills, but the specifics of this relationship have been difficult to ascertain because of a lack of consensus in findings. This confusion may be in part because researchers have assessed both executive function and mathematics in a variety of ways. Examples include executive function assessment strategies ranging from a single face-to-face measure to a panel of measures, with mathematics assessed primarily through measures of numeracy. The following longitudinal study examined this relationship through the use of a comprehensive panel of face-to-face executive function measures, as well as a broader measure of mathematics performance than has typically been used, one including numeracy and geometry. Time 1 assessments were made at the beginning of the school year. Time 2 assessments were repeated about six months later (*M* = 5.61 mos., *SD* = 1.12). One hundred eighteen children (61 girls), ages 39 to 68 months (*M* =

52.58, *SD* = 6.35), and their preschool teachers were included in data collection, with children from both rural (four centers; sample size, *n* = 64) and urban (three centers; sample size, *n* = 54) areas. Teachers completed a paper-and-pencil assessment of child executive function, and children responded to a panel of face-to-face executive function measures and a measure of math proficiency, assessing both numeracy and geometry skills. This dissertation focused on comparisons between analytic strategies in measuring executive function (paper-and-pencil and face-to-face) during the preschool years and how these strategies differed in predicting mathematical performance. Results suggest the age of the child needs to be considered when selecting measures and when determining analytic strategies. For example, the predictive power of measures varied from statistical significance to nonsignificance, or vice versa, between assessment periods about six months apart. Additionally, the age of the child determined if using a panel of face-to-face executive function measures resulted in a statistically significance change in *R*-square beyond the use of a single measure, with differences in timing between predicting numeracy and geometry skill. Almost all executive function measures included in this study were more predictive of numeracy skill than geometry skill, with evidence that geometry skill is connected to inhibitory control. Differences between rural and urban children were found on numeracy skill and working memory ability, but not on geometry skill. There was a statistically significant difference by gender on a measure of inhibitory control (Porteus Maze Test), with boys scoring higher than girls in this sample.

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PUBLIC ABSTRACT

Comparing the Predictive Power of Executive Function Assessment Strategies on Preschool Mathematics Performance

Jacob A. Esplin, Doctor of Philosophy

A child's executive function (aspects: working memory, response inhibition, and set-shifting between sets of rules) capabilities have been found to strongly relate to their mathematics skills. However, while the relationship has been strongly supported by researchers, a consensus has not been reached regarding the specifics of the relationship between executive function and math skills, including which executive function aspect is most predictive of mathematical performance and the differences in said relationship that might be found when examining both numeracy, such as counting skills and basic operations, and geometry skills. The lack of consensus may be in part because researchers have assessed both executive function and mathematics in a variety of ways. To address the consensus issue, this study used a panel of face-to-face measures of executive function, a paper-and-pencil measure of executive function, and a broader measure of mathematical performance than has typically been used, one including numeracy and geometry. Using a longitudinal approach, with two assessment periods about six months apart (M = 5.61 mos., SD = 1.12), this study examined this relationship among 118 children (61 girls), ages 39 to 68 months (M = 52.58, SD = 6.35), living in both rural (n = 64) and urban (n = 54) areas in a state in the western United States. A longitudinal approach allowed for comparisons between results from the two assessment periods. Results suggest that while numeracy and geometry skill among preschool-age children are connected, there are some independent elements. Additionally, because of rapid cognitive growth, age is an important factor when selecting both assessments and analytic strategies, as statistically significant variations in the predictive power of measures and strategies occurred between assessment periods. Connections between younger children's executive function and numeracy skills appeared to be best assessed through a non-number-based measure, older children's numeracy ability can be predicted by a greater variety of executive function measures. Face-to-face executive function measures included in this study were more predictive of numeracy skill than geometry skill, and geometry skill appears to be connected to inhibitory control. Differences between rural and urban children were found on numeracy skill and working memory ability, but not on geometry skill. Statistically significant differences by gender were found on an inhibitory control measure, with boys scoring higher than girls in our sample.

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Jacob A. Esplin

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CHAPTER 1

INTRODUCTION

Executive function (EF) is a cognitive process that supports holding and manipulating data (working memory), the self-regulation of thoughts and emotions, including the ability to overcoming a predominant response (inhibitory control), and alternating between tasks or mental sets (set-shifting; Anderson, Jacobs, & Anderson, 2010; Clements, Sarama, & Germeroth, 2016; Gioia, Espy, & Isquith, 2003; Miyake et al., 2000). EF is an important process to study, particularly in the preschool years, as EF has been shown to provide foundational support for early developing cognitive behaviors (Clark et al., 2016), and influences adaptive behavior (Clark, Prior, & Kinsella, 2002), self-control (Eisenberg & Zhou, 2016), academic achievement (Shaul & Schwartz, 2014), and social functioning (Teepe, Molenaar, Oostdam, Fukkink, & Verhoeven, 2017).

Researchers studying EF have employed differing assessment strategies, which are as follows. For face-to-face assessment of EF, some studies (e.g., White & Carlson, 2016) rely on a single EF assessment while others use a battery of face-to-face EF assessments (e.g., Miyake et al., 2000). Paper-and-pencil measures of EF, often completed by parents and/or teachers, have been used in studies (e.g., van Mil et al., 2012) as a solitary assessment of EF, as part of a collection of related measures (e.g., Braun et al., 2011), or in addition to one of the face-to-face strategies mentioned previously (e.g., Isquith, Crawford, Espy, & Gioia, 2005). The purpose of this study is to explore the differential predictiveness of EF assessment strategies regarding proficiency in numeracy and geometry. The relationship between numeracy and EF is a connection strongly supported by research (e.g., Best, Miller, & Naglieri, 2011; Fuhs, Nesbitt, Farran, & Dong, 2014; Mazzocco & Kover, 2007; McClelland et al., 2007; Schmitt, Geldhof, Purpura, Duncan, & McClelland, 2017; Watts et al., 2015), but the relationship between geometry and EF has been less well established. Because EF develops rapidly during the preschool years, it is helpful to research, practice, and the construction of theory, to know which assessment strategy at which time, is more effective at capturing the most variability in predicting math outcomes.

Theoretical Framework

Bronfenbrenner's bioecological model of human development is used in this study to explain how a child's development can be affected by environmental influences through four interrelated factors: proximal processes, personal and biological characteristics, contextual influences, and the element of time (Bronfenbrenner & Morris, 2006). Known as the Process-Person-Context-Time (PPCT) model, this theory provides explanations for differences resulting from contextual influences and certain demographic factors, such as age and gender, which are classified as *person* characteristics. Bronfenbrenner stated these characteristics are "so pervasive in affecting future development that their possible influence routinely needs to be considered in relation to the particular phenomenon under investigation" (Bronfenbrenner & Morris, 2006, p. 814). Bronfenbrenner and Morris (2006) also identified active behavioral dispositions as the characteristic of the person most likely to influence future development. Examples of developmentally disruptive dispositions mentioned include impulsiveness, distractibility, and the inability to delay gratification, all of which appear connected to the EF aspect of inhibitory control. Likewise, Bronfenbrenner's model includes the complicated synergism of place, subculture, developmental status, and behaviors, such as that possibly found when looking at urban and rural differences among EF and math abilities for preschool children.

What is Known?

Between 3 to 5 years of age qualitative changes occur in regions of the brain underlying complex cognitive processes (Bell, Wolfe, & Adkins, 2007), with rapid change demonstrated for the three aspects of EF: working memory (e.g., Espy & Bull, 2005), inhibitory control (e.g., Wiebe, Sheffield, & Espy, 2012), and set-shifting (e.g., Clark et al., 2013). EF skills are initially rudimentary (Diamond, 2006), develop rapidly during the preschool years (Zelazo & Carlson, 2012), become more complex as the aspects become coordinated (Clark et al., 2016; Fischer & Rose, 1994), and more efficient as the child ages (Carlson, 2005). Rapid development of EF during this period has been identified for working memory (e.g., Ewing-Cobbs, Prasad, Landry, Kramer, & DeLeon, 2004), inhibitory control (e.g., Lemmon & Moore, 2007), and set-shifting (e.g., Hongwanishkul, Happaney, Lee, & Zelazo, 2005), resulting in performance differences between children less than a year apart in age (e.g., Carlson, 2005; Deák, Rey, & Pick, 2004; Müller, Dick, Gela, Overton, & Zelazo, 2006). In longitudinal studies examining EF, such rapid development may have resulted in the lack of measurement invariance found for all (Nelson et al., 2016) or some (Willoughby, Wirth, & Blair, 2012) measures during the preschool years.

Research suggests the relationship between EF and mathematics, while remaining strong, changes and evolves during the preschool years as children develop more complex cognitive skills (e.g., Fuhs et al., 2014; Jacob & Parkinson, 2015; Schmitt et al., 2017). Longitudinal studies exploring these relationships in preschoolers have found strong predictive relationships between EF, literacy, and numeracy (Welsh, Nix, Blair, Bierman, & Nelson, 2010), as well as bidirectional relationships between EF and mathematics (Fuhs et al., 2014; Schmitt et al., 2017). However, in the above studies, mathematics was only assessed in terms of numeracy skills, such as counting, basic operations, number recognition, and sequencing. They neglected to include a more comprehensive measure of mathematics, including geometry skills such as shape recognition, spatial imagery, and patterns, as had been recommended by the National Council of Teachers of Mathematics (NCTM, 2000). While there has been limited research targeting other mathematical areas, including connecting number knowledge to EF and spatial awareness (Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014) and a broadly focused mathematics intervention, including numeracy, geometry, and spatial skills, affected early EF (Weiland & Yoshikawa, 2013), few studies exploring the relationship between EF and mathematics skills have utilized a broad measure of mathematics skill.

Bronfenbrenner's PPCT model (Bronfenbrenner & Morris, 2006) posits that contextual influences affect children's development, and researchers have found evidence supporting this influence on children's EF and mathematics skill. For example, research has found key demographic differences between the microsystems of rural and urban populations on two indicators of socioeconomic status (SES), income (e.g., Lichter & Johnson, 2007; Miller, Votruba-Drzal, & Setodji, 2013; O'Hare & Mather, 2008) and parental education level (e.g., Miller & Votruba-Drzal, 2013; Provasnik et al., 2007; Wirt, et al., 2004), with urban populations typically having greater income and higher education level. Differences in microsystems for rural and urban populations are significant as SES has been found to influence children's cognitive development and academic achievement (e.g., Bradley & Corwyn, 2002; Hackman, Gallop, Evans, & Farah, 2015; Miller et al., 2013). However, contextual differences between rural and urban populations include more than just differences in the microsystem. For example, additional dissimilarities include macrosystem effects, or differences in culture. Potential macrosystem differences may include observed differences in mathematics achievement beyond the influence of family SES (Graham & Provost, 2012), differing educational expectations (e.g., rural parents have less emphasis on children's academic achievement: (Lampard, Voigt, & Bornstein, 2000), and school readiness disparities (e.g., urban children being more prepared than rural counterparts: Miller & Votruba-Drzal, 2013). Additionally, this study postulates, other macrosystem effects may involve relatively unmeasured differences of stimuli, access to resources, use of space, and some elements of cultural diversity found between rural and urban populations.

Beyond the contextual influences, *person* characteristics from Bronfenbrenner's PPCT model (Bronfenbrenner & Morris, 2006) that have been connected to EF and mathematical skill include age, as discussed previously (e.g., Carlson, 2005; Deák et al., 2004; Müller et al., 2006), and gender. Past research suggests preschool-age girls have a modest advantage in EF when using a unitary model (e.g., Wiebe, Espy, & Charak, 2008), and perform better on inhibitory control tasks when looking for differences by EF aspect (e.g., Bull, Espy, Wiebe, Sheffield, & Nelson, 2011; Carlson & Moses, 2001; Matthews, Ponitz, & Morrison, 2009; Olson, Sameroff, Kerr, Lopez, & Wellman, 2005). However, other studies do not support gender differences in EF performance (Brocki & Bohlin, 2004; Deák et al., 2004; Hughes & Ensor, 2005). Gender differences in mathematical skill have also been found, with results varying by the age of the child (for more information, see Reardon, Fahle, Kalogrides, Podolsky, & Zárate, 2018).

What is Not Known?

While relationships between EF and mathematics have been frequently studied, variations in assessment strategy may have resulted in the dissimilar findings found in studies examining similar associations. The three EF assessment strategies typically used during the preschool years, as demonstrated by these frequently cited studies, include: a single face-to-face measure (e.g., McClelland et al., 2007), a panel of face-to-face measures (e.g., Bull, et al., 2011), and a panel of face-to-face measures and a teacher and/or parent paper-and-pencil measure (e.g., Clark, Pritchard, & Woodward, 2010). However, through using differing assessment strategies, experts in the field have found seemingly contradictory evidence regarding which aspects of EF are most predictive of mathematical performance: (a) working memory and inhibitory control (McClelland et al., 2007; a single face-to-face measure); (b) inhibitory control and to a lesser degree working memory (Espy et al., 2004; a panel of face-to-face measures); (c) inhibitory control and set-shifting (Blair & Razza, 2007; two face-to-face measures); or (d) significant influence from all three aspects (Purpura, Schmitt, & Ganley, 2017; a panel of face-to-face measures). With development occurring so rapidly, and significant differences found even between younger threes and older threes (Carlson, 2005), it would be helpful to understand the variation across time, if any, in the predictive power of various strategies.

Most researchers studying preschool-age mathematics utilize measures only designed to assess numeracy skills (e.g., TEMA-3; Ginsburg & Baroody, 2003), overlooking the complexity of mathematical content areas that could be assessed as outlined by national mathematics advisory groups (NCTM, 2000; Geary et al., 2008). While more comprehensive measures of early mathematics are available (e.g., Clements & Sarama, 2011a; Klein, Starkey, & Wakeley, 2000), use of these types of measures is less common. While some scholars (e.g., Clements et al., 2016) have addressed the need to better understand the relationship between EF and aspects of mathematics (e.g., numeracy and geometry), there has been no known attempts to connect these to EF. And as the developing child is greatly influenced by their environment, as demonstrated by the PPCT model (Bronfenbrenner & Morris, 2006), it is important to determine how this influence affects the predictive power of various EF assessment strategies in predicting mathematical performance.

Purpose of the Study

The purpose of this study was to examine the relationship between preschool-age EF and mathematical performance, with a focus on both numeracy and geometry skills, and to compare the differing assessment strategies typically used. The inconclusive findings previously reported, with different EF aspects connected differently to mathematical performance, seem to contradict one another, but may be explained by differences in child age and in assessment strategy. Additionally, no studies have examined the relationship between the aspects of EF and geometry skill. This study attempted to better understand these relationships through the use of a comprehensive panel of face-to-face EF assessments, a paper-and-pencil teacher completed measure of

EF, as well as a broader measure of mathematical performance than is typically used, assessing both numeracy and geometry skill. Face-to-face EF measures included two measures of set-shifting (Dimensional Change Card Sort: Frye, Zelazo, & Palfai, 1995; Tower of Hanoi: Klahr, 1978), two inhibitory control tasks (Porteus Maze Task: Porteus, 1965; Head Toes Knees Shoulders: Ponitz, McClelland, Matthews, & Morrison, 2009), and a working memory measure (forward-digit span). The paper-and-pencil measure used in this study, and completed by the child's preschool teacher, was the Behavior Rating Inventory of Executive Function-Preschool Version (Gioia et al., 2003).

Because of rapid development in both EF capabilities and mathematical skill during the preschool years (e.g., Geary et al., 2008; Zelazo & Carlson, 2012), and scholars recognizing that age strongly influences children's performance on EF measures (Carlson, 2005; Wiebe et al., 2011), a longitudinal design was selected to provide insight into how the relationship between these constructs changes across time. As far as is known this is among the first longitudinal studies to take such a broad approach in assessing both EF and mathematical performance among preschoolers, and allowed us to compare results from assessments taken about six months apart. Taking Bronfenbrenner's PPCT model (Bronfenbrenner & Morris, 2006) into account, differences by contextual influences, such as found in rural and urban environments, and *person* characteristics, such as gender and age, are included in analyses.

Research Questions

1. How are the various executive function measures and the measure of mathematical performance (numeracy and geometry) related to one another?

2. Are there differences in the predictive power of various executive function assessment strategies (single measure, face-to-face panel, face-to-face panel and paper-and-pencil) on preschool-age mathematical performance (numeracy and geometry)?

3. How does the predictive power of various executive function assessment strategies (single measure, face-to-face panel, face-to-face panel and paper-and-pencil) change by age, gender, or rural/urban categorization relative to preschool-age mathematical performance (numeracy and geometry)?

CHAPTER II

LITERATURE REVIEW

Chapter II begins with a review of the literature on executive function, including its rapid development during the preschool years. Growth is reviewed for the three traditionally recognized aspects of executive function: working memory, inhibitory control, and set-shifting (Miyake et al., 2000). Next are sections outlining how both executive function and mathematics are assessed during the preschool years. The interrelatedness of executive function and mathematics is discussed, including the variations in analytic strategies used to measure both constructs. The chapter concludes with a discussion of how contextual influences may influence outcomes.

Executive Function

Executive function (EF) is a higher order, goal-oriented, top-down cognitive process, also referred to as executive control or cognitive control (Wiebe et al., 2011). EF traditionally consists of three related but distinct aspects (e.g., Diamond, 2013; Miyake et al., 2000): working memory, inhibitory control (including self-control [behavioral inhibition] and interference control [cognitive inhibition and selective attention]; Diamond, 2013), and set-shifting (also called cognitive flexibility, mental flexibility, attentional flexibly, or mental set-shifting; Diamond, 2013). Working memory includes the holding and manipulating of information and recalling it to help perform complex tasks (Allan, Allan, Lerner, Farrington, & Lonigan, 2015). Inhibitory control is the ability to suppress a predominant response (e.g., motor reaction) or to ignore interfering, nonrelevant stimuli or information, relative to successfully completing a goal-directed behavior (Anderson et al., 2010; Rothbart & Bates, 2006). Set-shifting requires changes in attention in response to situational demands and shifting focus between sets, such as shifting between different tasks, shifting between different sets of rules (e.g., playing offense or defense depending on which team has control of the ball; Diamond, 2013). EF aspects appear to emerge in a gradual process, starting with more simplistic processes initially (e.g., remembering where desired toy was hidden by researchers; Sun, Mohay, & O'Callaghan, 2009) to more complex self-regulatory behaviors developed during early childhood (Diamond, 1991; Garon, Bryson, & Smith, 2008). Although the relationship between EF and preschool mathematics have been examined by multiple researchers, the relationship between EF and a broader measure of preschool mathematics including geometry and algebra, has not been as well studied, particularly with regard to developmental changes in EF and mathematical capabilities that occur across time. The purpose of this study was to assess relationships and changes in relationships between EF and mathematics longitudinally. A broad panel of EF measures was used to determine if certain aspects of EF relate to mathematics at one age rather than another or if they relate to some types of mathematics (e.g. numeracy vs. geometry or algebra) but not others.

EF is important to study as it plays an essential role in cognition, educational attainment, and social functioning (Blair, 2002; Espy et al., 2004; Teepe et al., 2017). EF develops rapidly in the preschool years (Zelazo & Carlson, 2012), and has a substantial influence on a child's developmental trajectory, including academic achievement and emotional regulation (Raver & Blair, 2016). Because this is a longitudinal study involving three-year-old children, the intent was to selected EF measures for working memory, set-shifting, and inhibition that might be sensitive to manifestations of EF in younger children and robust across development. Multiple measures were involved in order to assess various possible contributions to different mathematical skills (i.e., numeracy, geometry).

Executive Function Development During Preschool Years

EF is essential for both mental (e.g., Diamond, 2013) and physical (e.g., Millar, Barnes, & Beaver, 2011) health, and for school success (e.g., Duncan et al., 2007) and readiness (e.g., Best et al., 2011); because EF was thought to develop in adolescence (e.g., Golden, 1981), the research of EF during the preschool years has only been studied since the late nineteen-eighties (Garon et al., 2008). Although rudimentary EF skills develop during infancy and toddlerhood (The Society for Research in Child Development, 2014), it is during the preschool years that these skills become coordinated (Clark et al., 2016; Fischer & Rose, 1994), more efficient (Carlson, 2005), and develop along different developmental trajectories (Diamond, 2002). Garon and colleagues (2008) posited that it is the coordination of component EFs, and the capability to have one operate on another, driving rapid EF development between three to five years of age. Of note, while some researchers feel that the earliest EF functions manifest as a single construct that differentiates with development experiences (Espy et al., 2016); others, however, feel this notion may not have the methodological support it needs (Willoughby, 2016). Thus, the area is active with controversy, making additional research necessary. Rapid development, across working memory, inhibitory control, and set-shifting, will now be demonstrated with references to preschool-age children.

Working memory. One of the most widely used and accepted working memory models is by Baddeley and Hitch (1974). Baddeley's updated model (2000) consists of four components: the central executive which works as an attentional controller, two working memory storage buffers (the phonological loop and visual-spatial sketchpad), and an episodic buffer that retrieves and feeds information into long term memory. The two memory storage buffers, identified as the phonological loop and visual-spatial sketchpad, develop rapidly during the preschool years, improving working memory abilities (Bull, Espy, & Senn, 2004; Espy & Bull, 2005; Ewing-Cobbs, et al., 2004; Gathercole, 1998; Keenan, 1998; Kemps, De Rammelaere, & Desmet, 2000). Improvement between 3 and 5 years of age on face-to-face tasks has been found on digit or word span tasks (e.g., Bull et al., 2004; Espy & Bull, 2005; Gathercole, 1998), spatial or object span tasks (e.g., Ewing-Cobbs et al., 2004; Keenan, 1998; Kemps et al., 2000), spatial and object memory (Diamond, 1991; Ewing-Cobbs et al., 2004; Luciana & Nelson, 2002), and the ability to track and update a large number of items (Hongwanishkul, et al., 2005). While frequently assessed through a face-to-face assessment, paper-and-pencil assessments completed by parent and/or teacher are also used. While working memory has frequently been identified as the EF aspect more strongly connected to numeracy skills (Clements et al., 2016), it is unknown if this relationship will remain when a more comprehensive measure of mathematics is used in a longitudinal study.

Inhibitory control. The restraining or withholding of a motor response is extensively researched in preschoolers, but, because of difficulties in designing a pure assessment of only one aspect of EF, many inhibitory control tasks also involve working memory (Garon et al., 2008). Garon et al. (2008) defined inhibitory control tasks involving minimal working memory input as *simple* and those requiring moderate working memory input as *complex*. While both inhibitory control tasks are traditionally assessed using face-to-face tasks, parent and/or teacher report through a paper-and-pencil assessment can also be used.

Simple inhibitory control tasks. One popular inhibitory control measure for preschoolers is the delay of gratification task with waiting and choice variants (Mischel, 1974). In the waiting variant, which offers one treat now or two if the child waits the full period, Carlson (2005) found great improvements with 85% of 3-year-old children suppressing for one minute and 72% of 4-year-old children suppressing for 5 minutes. For the choice variant, which allows preschoolers to choose a small reward now or a larger reward later, age differences were found in the number that chose to delay for the larger reward (Lemmon & Moore, 2007). As these tasks require minimal working memory input, simple tasks may be a better reflection of inhibitory control (Best & Miller, 2010).

Complex inhibitory control tasks. Complex inhibitory control tasks require the participant to hold an arbitrary rule in mind, respond based on this rule, and inhibit a preponderant response (Garon et al., 2008). Studies have found age differences on these tasks for 3- to 5-year-old children (e.g., Carlson, 2005; Carlson & Moses, 2001; Diamond, 1991; Keenan, 1998; Wiebe et al., 2012), and Carlson (2005) even found differences between young threes (36-41 months) and older threes (42-47 months). Carlson (2005) found that while 51% of young 3-year-olds were able to pass a complex inhibitory control task, 76% of older 3-year-olds passed it, implying an increase in inhibitory control ability during this developmental period.

In addition to working memory, inhibitory control has been consistently connected to mathematical performance, specifically numeracy skills (Clements et al., 2016). To better understand this connection in the presence of other EF measures, two inhibitory control measures (Head Toes Knees Shoulders: Ponitz et al., 2009; Porteus Maze Test: Porteus, 1965) were included in the panel of EF measures.

Set-shifting. Set-shifting, or shift, is the ability to switch between mental sets, and is dependent on working memory and inhibitory control operating on one another, making it the most complex aspect of EF (Chevalier et al., 2012). First, the participant forms an association between a certain stimulus and a response. A focus on the relevant stimulus is required, ignoring distractions, and using working memory to retain this mental set (Miyake et al., 2000). Second, a new mental set is introduced that is in conflict with the original. The two types of set-shifting tasks are *attention shifting*, which changes the rule based on an aspect of the stimuli, and *response shifting*, which influences the selection of a motor response (Rushworth, Passingham, & Nobre, 2005). While these tasks are often administered face-to-face, set-shifting can also be assessed through teacher or parent report on a paper-and-pencil assessment.

Attention shifting. The dimensional change card sort (DCCS; Frye et al., 1995; Zelazo, 2006) requires participants to initially sort bivariate cards according to one dimension (i.e., color), followed by sorting by the other dimension (i.e., shape; for more detailed explanation of DCCS, see methods section below). While most 3-year-olds can sort by the first rule (i.e., color) they have difficulty shifting to the new rule (i.e., shape), but by 4 years of age children have developed the ability to shift successfully (Carlson, 2005; Carlson & Moses, 2001; Frye et al., 1995; Hongwanishkul et al., 2005; Müller et al., 2006). An increase in attention shifting performance from three to four years is not unique to the DCCS and has been replicated in other studies (e.g., Clark et al., 2013).

Response shifting. The Tower of Hanoi (TOH: Klahr, 1978; Simon, 1975) measure is an assessment of response shifting. The TOH task requires the participant to shift between different goals while moving disks to form a configuration matching the examiners (for a more detailed explanation of TOH, see methods section below). Age differences for three- to five-year-olds were found on TOH performance (Klahr, 2012), and on other response shifting tasks (e.g., Espy, Kaufmann, Glisky, & McDiarmid, 2001; Hughes, 1998; Schutte, Spencer, & Schöner, 2003; Thelen, Schöner, Scheier, & Smith 2001).

The rapid development of EF occurring between 3 to 5 years of age has been identified for working memory (e.g., Ewing-Cobbs et al., 2004); inhibitory control, both simple (e.g., Lemmon & Moore, 2007) and complex (e.g., Carlson, 2005); and set shifting, both attention shifting (e.g., Hongwanishkul et al., 2005) and response shifting (e.g., Espy et al., 2001). The rate of development can result in performance differences between children less than a year apart in age (e.g., Carlson, 2005; Deák et al., 2004; Müller et al., 2006). In longitudinal studies examining EF, this rapid development may have resulted in the lack of measurement invariance found for all (Nelson et al., 2016) or some (Willoughby et al., 2012) measures. While all aspects of EF can be assessed through face-to-face assessments, and might traditionally be assessed that way, paper-and-pencil assessments are also available.

One theory for what drives this rapid development from three to five years of age is the Cognitive Complexity and Control Theory – revised (CCC-r; Zelazo, Müller, Frye, & Marcovitch, 2003). According to the CCC-r it is inhibition that allows for more developed response selection. The central claim of CCC-r is that individuals are able to successfully override a preponderant response through recognizing conflicting rules, using working memory to consider them in contradistinction, and choosing a response in line with a current goal, switching mental sets if needed (Doebel & Zelazo, 2016). Perseveration occurs when children are unable to pause, reflect, and inhibit a dominant response. The ability to override perseveration requires higher-order rules for switching between contradictory rules, which is possible through developmental increases in reflection (Doebel & Zelazo, 2015). The ability to reflect does not develop in a stage-like fashion, but rather the likelihood of it occurring increases with age and experience (Marcovitch & Zelazo, 2009).

EF is an important construct to study as it plays an essential role in social functioning, educational attainment, and cognition (Blair, 2002; Espy et al., 2004; Teepe et al., 2017). EF develops rapidly in the preschool years (Zelazo & Carlson, 2012), and has a substantial influence on a child's developmental trajectory, including academic achievement and emotional regulation (Raver & Blair, 2016). While EF has a considerable impact on a child's developmental trajectory, including academic achievement and emotional regulation (Raver & Blair, 2016), it can be difficult to understand because it develops rapidly in the preschool years (Zelazo & Carlson, 2012). Because this is a longitudinal study involving preschool-age children, the intent was to select EF measures for working memory, set-shifting, and inhibition that might be sensitive to manifestations of EF in younger children and robust across development. A multiple measure approach has been suggested to achieve a reliable EF score for preschool-age children (Wiebe et al., 2011). Multiple measures were also involved to assess various possible contributions to different mathematical skills (i.e., numeracy, geometry).

Measurement of Preschool-Age Executive Function

One challenge in measuring preschool-age EF has been the development of developmentally appropriate measures (Carlson, 2005), as many adult assessments of EF are too linguistically demanding (Hughes & Graham, 2002) or involve complex tasks that, when simplified for young children, no longer measure the targeted EF component (Garon et al., 2008). Researchers studying preschool-age EF will traditionally follow one of two approaches when determining their conceptual view of EF assessment: componential or unitary. For example, in an attempt to parse the influence of nonexecutive skills and EF, some researchers utilize a battery of tests designed to measure the various aspects of EF using different approaches (Wiebe et al., 2011). An example is demonstrated as Carlson (2005) reported utilizing 11 EF tasks in one study. For researchers that view the assessment of EF as measuring a unitary construct (e.g., Espy et al., 2016), measures have been designed (e.g., Minnesota Executive Function Scale; Carlson & Zelazo, 2014) that provide a single, overall EF score, rather than scores for each EF aspect. Others with this viewpoint may add some redundancy by employing face-to-face EF measures and a measure of EF completed by a parent or teacher. The assumption is that multiple reports provide complementary views of a child’s functioning (Achenbach, McConaughy, & Howell, 1987). Because of the literature above, this study utilized a panel of five face-to-face EF measures selected to assess aspects of EF in differing ways, with an additional paper-and-pencil measure given to both parents and preschool teachers. Because of the difficulties mentioned above in designing a measure of EF for preschoolers that only assesses one aspect of EF (e.g., inhibitory control measures involving working memory; Garon et al., 2008), these measures provide some overlap in the aspects they are reported to assess. Additionally, because they are reported to assess all three aspects of EF, two of the measures selected for this study, the Dimensional Change Card Sort (DCCS: Frye et al., 1995; Zelazo, 2006) and the Head Toes Knees Shoulders (HTKS: Ponitz et al., 2009), have been used in studies as a solitary measure of EF (e.g., DCCS: Buss & Spencer, 2014; HTKS: Ivrendi, 2011). The inclusion of these measures in this study will provide for comparisons between these solitary measures and the panel of measures in predicting mathematical performance. Measures included in this study included: two set-shifting measures, one assessing attention shifting (Dimensional Change Card Sort: Frye et al. 1995; Zelazo, 2006) and one for response shifting (Tower of Hanoi: Klahr, 1978); two inhibitory control tasks, both simple (Porteus Maze Task: Porteus, 1965) and complex (Head Toes Knees Shoulders: Ponitz et al., 2009); and a working memory measure (forward-digit span). The paper-and-pencil measure used in this study, with components assessing all three aspects of EF, was the Behavior Rating Inventory of Executive Function-Preschool Version (Gioia et al., 2003), and was completed by the child's preschool teacher.

Measuring Mathematics in the Preschool Years

Similar to EF, mathematics can be conceptualized and measured in a variety of ways. A traditional approach assesses mathematics skills, such as numerical abilities (e.g., counting, basic operations), using measures such as the Test of Early Mathematics Ability (TEMA-3; Ginsburg & Baroody, 2003) or the Woodcock Johnson-III Applied Problems subtest (WJ-III; Woodcock, McGrew, & Mather, 2001). Other assessments, like the Test of Spatial Awareness (TOSA; Verdine et al., 2014), focus entirely on spatial or other non-numerical skills. For those seeking to address a multitude of skill types, including geometry, a domain frequently overlooked (Clements & Sarama, 2011b), researchers can use the Tools for Early Assessment in Math (TEAM; Clements & Sarama, 2011a), which also includes questions regarding number recognition, and verbal and object counting, or the Child Math Assessment (CMA; Klein et al., 2000) which was designed to address arithmetic, space/geometry, measurement, patterns, and logical relations.

In 2006, the National Council of Teachers of Mathematics (NCTM, 2006) outlined prekindergarten standards and made curriculum recommendations with an emphasis on numbers and operations, geometry, and measurement during the preschool years. Likewise, the National Mathematics Advisory Panel's report includes discussion of skill development for preschoolers in arithmetic, fractions, estimation, geometry, and algebra (Geary et al., 2008). Based on recommendations from these experts, mathematics during the preschool years is more than numeracy skills, and excluding other areas from assessment (e.g., geometry) may result in an incomplete assessment of children's capabilities. In fact, in the state that this study took place, early childhood core standards designed for preschoolers, includes geometry. While more attention is focused on numerical skills, such as knowing, comparing, and the sequence of numbers, geometry is included as an area of focus. The geometry standards for preschoolers are focused on shapes, specifically identifying and describing shapes, as well as the ability to compare, create, and compose shapes. Thus, in this study mathematics was measured more broadly by using the TEAM. Because the TEAM assesses algebra, geometry, measurement, data analyses, and numbers and operations, and follows the developmental progression of mathematical learning (Clements & Sarama, 2011a), it should allow more accuracy in assessing developing relationships between EF and mathematical performance.

Executive Function and Mathematics

Links between early mathematics performance and EF during the preschool years have been well established (e.g., Best et al., 2011; Fuhs et al., 2014; McClelland et al., 2007; Purpura et al., 2017; Schmitt et al., 2017; Watts et al., 2015). A review of past research detailing the directionality of causal relationships between mathematics and EF (Clements et al., 2016) provides insight into the complexity of these links. Examples include EF accounting for a large part of the variance in children's mathematics skills (e.g., Clark et al., 2010); EF predicting mathematics performance (e.g., Best et al., 2011; Jacob & Parkinson, 2015); EF development aided by early mathematics skills (e.g., McClelland et al., 2007); and EF and mathematics in a bidirectional relationship (e.g., Fuhs et al., 2014; Schmitt et al., 2017; Welsh et al., 2010). The previously cited studies used both longitudinal (e.g., Best et al., 2011; Clark et al., 2010) and meta-analytic (Jacob & Parkinson, 2015) designs.

Researchers have tried to determine which of the three aspects of EF (working memory, inhibitory control, set-shifting) are more predictive of preschool-age mathematical performance, and have had varying results. McClelland and associates (2007) reported preschoolers with higher working memory and inhibitory control scores achieved higher levels in mathematics. Espy and colleagues (2004), found evidence suggesting inhibitory control, and to a lesser degree working memory, was predictive of mathematical skills. Similar connections have been reported for school-age children (e.g., Gathercole & Pickering, 2000), although for this group, others (Van der Ven, Kroesbergen, Boom, & Leseman, 2012) reported working memory was the predictive EF aspect. In comparison, Blair and Razza (2007) found it was inhibitory control and set-shifting that were related to measures of math for 3- to 5-year-old children. Demonstrating the relatedness of EF aspects, Bull and Scerif (2001) found children with lower mathematical abilities also scored lower on inhibition and working memory, causing difficulty with set-shifting. While some research has indicated most EF processes are related to mathematical performance (Bull & Scerif, 2001; Purpura et al., 2017), working memory and inhibitory control are more consistently connected to predicting mathematical performance for preschoolers (Clements et al., 2016).

The variation in strategies used to assess EF is demonstrated by reviewing the methods used by researchers examining the relationship between EF and mathematical performance. For example among studies cited above, one study used just one face-to-face unitary measure of EF (Head-to-Toes Task: Ponitz et al., 2008) in analyses (McClelland et al., 2007), another (Purpura et al., 2017) used one face-to-face measure for each aspect of EF (a modified Stroop-like task: Archibald & Kerns, 1999; Automated Working Memory Assessment: Alloway, 2007; card sorting task based on DCCS: Frye et al., 1995; Zelazo, 2006), and one study (Clark et al., 2010) that employed both face-to-face (Tower of Hanoi: Simon, 1975; Flexible Item Selection Task: Jacques & Zelazo, 2001; Shape School: Espy, 1997) and paper-and-pencil measures (Behavior Rating

Inventory of Executive Function – Preschool: Gioia et al., 2003) of EF. Others utilized a panel of face-to-face EF measures but with different approaches: one study created a latent variable of EF by combining nine EF measures (Bull et al., 2011), while two grouped nine EF measures into three factors of two to four measures each (Espy et al., 2004; Van der Ven et al., 2012). As this small sample of studies attests, it is evident that variation in assessment strategies is common. With the rapid EF development occurring between three and five years of age, it is important to understand the variation across time, if any, in the predictive power of various strategies. To address this issue, a panel of face-to-face measures was used so comparisons between strategies can occur. Because few researchers use paper-and-pencil parent and teacher report to assess child EF, a comparison will also be made between that method and the face-to-face measures in predicting mathematics development.

The relationship among EF and mathematics during the preschool years is complicated by the fact that most of the previously mentioned studies of EF and mathematics used measures of numeracy alone to assess mathematical performance. The need to assess other mathematical skills has been addressed by some authors (e.g., Clements et al., 2016; Fuhs et al., 2014; Schmitt et al., 2017). A handful of studies have examined the relationship between other areas of mathematics and EF (e.g., spatial awareness: Verdine et al., 2014; applied math problems: Weiland & Yoshikawa, 2013), but a more complete assessment of preschool mathematical performance, including the skills outlined by the NCTM (2006), is needed to more fully understand mathematics and EF in the preschool years. While researchers have examined the links between EF and mathematics for preschoolers, the present study is among the first longitudinal studies utilizing a panel of EF measures and a broad-based mathematical measure assessing both numeracy and geometry skills.

Influences on Development Through the Lens of Bronfenbrenner's Bioecological Model

In his bioecological model of human development, Bronfenbrenner focused on the influence of reciprocal interactions between organisms and their environment, including interactions with other people, objects, or symbols (Bronfenbrenner & Morris, 2006). Through these interactions, which he referred to as proximal processes, an individual learns about their environment and their role within it.

Bronfenbrenner's Process-Person-Context-Time (PPCT) model helps frame the complex interactions influencing a preschool-age child's development, including the proximal processes, personal and biological characteristics, contextual effects, and the element of time (Bronfenbrenner & Morris, 2006). The PPCT model is useful in understanding how these influences may lead to differences in EF and/or mathematics performance.

Proximal Processes

Proximal processes are the primary mechanisms behind human development, according to the PPCT model, because it is through interacting with others that an individual learns to make sense of their world and their place within it (Tudge, Mokrova, Hatfield, & Karnik, 2009). However, the strength of the influence these processes have on development is based on the other aspects of the PPCT model: characteristics of the developing individual; contextual influences, both intimate and remote; and the timing of proximal processes (Bronfenbrenner & Morris, 2006). The proximal process of preschool-age EF and mathematical skill development includes personal characteristics, such as the age and gender of the developing child, contextual influences from their environment, including interactions from home, school, and the lifestyles in rural and urban communities.

Person

The person aspect of Bronfenbrenner's PPCT model is defined as the personal characteristics of an individual (Bronfenbrenner & Morris, 2006), and can include certain demographic factors, called demand characteristics, including age and gender. Of interest to cognitive development are resource characteristics as they relate to the mental, social, emotional, and material resources provided to aid in development (Tudge et al., 2009). Resource characteristics are developmental assets, which include an individual's ability, knowledge, skill, and experience, that work to extend the domains in which proximal processes can influence an individual (Bronfenbrenner & Morris, 2006).

As has been stated above, the age of an individual needs to be considered when assessing EF, as performance differences have been found between children less than a year apart in age (e.g., Carlson, 2005; Deák et al., 2004; Müller et al., 2006). Another person aspect examined when researching EF is the influence of gender on development. Previous studies found evidence that preschool-age girls have a modest advantage in latent EF compared to boys (Wiebe et al., 2008) and that girls perform better on inhibitory control tasks, specifically those related to delaying gratification (e.g., Bull et al., 2011; Carlson & Moses, 2001; Matthews et al., 2009; Olson et al., 2005). However, other studies did not support gender differences in EF performance (Brocki & Bohlin, 2004; Deák et al., 2004). It is important to note that while all of the before mentioned studies primarily used face-to-face assessments of EF, rather than teacher and/or parent report, age was treated differently in each study. For example, Wiebe and colleagues (2008) split their preschool-age sample into an older and younger group, and found gender differences, while Deák and associates (2004) kept their sample of three- to five-year-old children together in analyses and did not find gender differences. Finding differences in EF performance by gender is supported by differences in socialization (Bull et al., 2011) or by males and females having different brain development trajectories (Gerber et al., 2009; Lenroot et al., 2007), but differences in study or analytical design may affect the likelihood of finding gender differences. If gender differences in EF performance exist, it would be important to know this when designing a research study to capture as much variation as possible. Gender differences in mathematical skill have also been found in past studies, with a math achievement gap favoring boys by the end of kindergarten (Reardon et al., 2018).

Contextual Influences

According to Bronfenbrenner, the influence of the context on an individual can be understood through the effects of four interrelated systems (Bronfenbrenner, 1979). The environment in which the developing individual spends most of their time is the microsystem, consisting of the home, school, and peer group environment. The connections and interrelation between multiple microsystems are what constitute the mesosystem. Environments that the individual is not a part of, but which still have influence, are part of the exosystem (e.g., parent’s stressful work environment). The final system, the macrosystem, includes the similarities in macro, meso, and exosystems representative of a specific culture, subculture, or broader social group, with shared values or belief systems. Within the macrosystem, similarities in experiences and beliefs within cultures are found, as well as differences between such groups.

Macrosystem influences have been identified for children based on whether they were from rural or urban households. An example is studies suggesting parents in urban areas tend to focus more on their children's academic school readiness skills (e.g., Miller & Votruba-Drzal, 2013) and have higher educational attainment expectations for their children compared to their peers in rural areas (e.g., Lampard et al., 2000). These examples represent how differences in educational outcomes found between rural and urban populations are in part influenced by the macrosystem of the area, and the differences in the philosophies of the two groups. Rural and urban differences might also be due to availability of services, resources, and degree of diversity.

In addition to the macrosystem, or cultural differences, between rural and urban populations, research frequently identifies microsystem differences within the home environment of rural and urban populations: income (e.g., Miller et al., 2013; Lichter & Johnson, 2007; O'Hare & Mather, 2008) and parental education level (e.g., Miller & Votruba-Drzal, 2013; Provasnik et al., 2007; Wirt et al., 2004). Indicators of socioeconomic status (SES), such as income and parental education level, have been found to influence children's cognitive development and academic achievement (e.g., Bradley & Corwyn, 2002; Hackman et al., 2015; Miller et al., 2013). Low SES has been found to negatively influence EF scores for preschool-age children (e.g., Blair et al., 2011; Raver, Blair, & Willoughby, 2013; Wiebe et al., 2011), although this might be mediated by the quality of the early childhood home environment (Hackman et al., 2015). Children with low SES often start kindergarten with lower mathematical achievement and progress more slowly during elementary and middle school, a trend more significant for rural children (Graham & Provost, 2012). Additionally, in some studies the contexts of low SES, or an exosystem effect, relate to less supportive parenting behaviors (Blair et al., 2011; Brody & Flor, 1998; Jackson, Brooks-Gunn, Huang, & Glassman, 2000).

Another microsystem difference is parental education level, which can vary between rural and urban populations. Studies have found that about a third of rural parents and about a quarter of urban parents reported a high school diploma was their highest educational attainment (Provasnik et al., 2007). Educational differences can be significant as lower maternal education, independent of other demographic differences, are usually predictive of lower EF in early and middle childhood (Hackman et al., 2015). For example, an inverse relationship was found between maternal education and impulsive behavior in children (Arán-Filippetti & Richaud de Minzi, 2012).

Time

The final aspect of the PPCT model, time, has three dimensions: microtime, mesotime, and macrotime (Bronfenbrenner & Morris, 2006). Microtime refers to continuity versus discontinuity that occurs during ongoing proximal processes, or simply what is occurring during proximal processes. Mesotime refers to how consistently interactions and activities occur in a person's environment, such as across days, weeks, and years. Macrotime, formerly referred to as the chronosystem in Bronfenbrenner's earlier work (1979), refers to how processes vary according to the age of an individual experiencing a specific event (e.g., experiencing 9-11 as an infant vs. as a 20-year-old).

An example of time influencing research, specifically mesotime, would be how the timing of an assessment period may influence performance. Assessments occurring after a prolonged period away from an academic setting, specifically after summer break, may be affected by learning loss, as is seen in elementary school children (e.g., Allington & McGill-Franzen, 2017; Cooper, Nye, Charlton, Lindsay, & Greathouse, 1996; Menard & Wilson, 2014). However, these studies suggest that this affect might be more significant for those from lower SES families (Allington & McGill-Franzen, 2017), a demonstration of contextual influences.

Summary

While scholars have found strong relationships between EF and mathematics, consensus has not been reached on which aspect of EF (working memory, inhibitory control, and set-shifting) significantly contributes to discrete aspects of mathematical performance (i.e., numeracy and geometry) or whether it is a combination of EF skills. Variation in measuring EF and mathematics as well as differences in assessment strategies have caused this disparity. Also, because of differences in EF development and mathematical performance by age, it is important to examine how these differences are influenced by the age of the child. A longitudinal study using a panel of EF measures and a broader measure of mathematical performance will provide insight into the relationship between EF and mathematics for some rural and urban preschoolers. The current study will also compare the predictive differences, or variance, claimed in mathematics scores by different EF assessment strategies frequently used in researching preschooler's mathematical abilities. Without a broader assessment of mathematics during the preschool years, and an appropriate strategy in assessing EF, researchers will continue to have seemingly contradictory findings, and the true relationship between these constructs will be unknown.

CHAPTER III

METHOD

Participants

The Studying Urban and Non-urban Behaviors, Environments, Attitudes, and Mathematics (SUNBEAM) project was designed to study rural and urban children's mathematical skills and EF in home and care environments. Urbanicity was determined by the Rural-Urban Continuum Codes (USDA, 2013). For this study, rural participants were recruited from areas categorized as a 7, designating counties with a population less than 20,000, while urban participants were from areas categorized as a 3, indicating a metro area with a population between 20,000 and 250,000. Children were recruited from state-licensed child care centers operating in rural (four centers; sample size, $n = 64$) and urban (three centers; sample size, $n = 54$) areas of a state in the western United States. Most were Caucasian, as is typical of the region. Once the sampling groups were identified, child care center directors were emailed a description of the study and asked if they would be willing to participate by distributing letters to parents and allowing a space for researchers at the center. If center directors agreed to participate, each potential parent participant was given a letter by the center describing the study. Parents that agreed to participate were then given a packet of measures including a demographic questionnaire and surveys regarding their child's EF. Incentives when assessing children included small items upon completion of the panel of face-to-face measures (i.e., decorative pencil or sticker of their choice), while parents received a brief explanation of study findings and a math themed book for their child. Centers that participated were given math manipulatives for their classroom.

Prior to each wave of data collection, researchers conducted practice sessions and reviewed administration guidelines for each measure. Co-project managers also reviewed guidelines with each other and with research assistants throughout data collection to maintain inter-rater reliability.

Measures

Face-to-face Measures of EF

All five face-to-face measures were given within one week's time and were administered individually. Co-project managers administered three EF measures (DCCS, Porteus Maze Test, TOH); research assistants administered two (HTKS, Forward-Digit Span). In order to avoid order effects, the order of assessments was randomized while preventing the administration of similar measures consecutively. Therefore, co-project managers administered assessments in one of sixty possible configurations, while research assistants were limited to four configurations because of fewer measurements.

Dimensional Change Card Sort (DCCS: Frye et al., 1995; Zelazo, 2006). The DCCS is possibly the most widely used EF measure for young children (Beck, Schaefer, Pang, & Carlson, 2011), and is similar to the Wisconsin Card Sorting Task (Berg, 1948), a measure referred to as the gold standard in measuring EF in adults (Clark et al., 2016). The DCCS is a nonverbal task requiring children to shift their attention between two rule sets. Children are required to sort a series of bivalent test cards, first by one dimension (color), then by the other (shape). For example, during the pre-switch phase, the children are shown a card with either a red star or a blue circle. They are told they are playing the color game and are told to place the card in the tray with the matching color; one tray is identified with a target card displaying a blue star and one tray with a red circle. After six cards have been sorted by color, they proceed to the post-switch trial and play the shape game using the same cards and trays. For the pre-switch phase, correct would be by color (i.e., blue circle test card with blue star target card), for the post-switch phase, correct would be by shape (i.e., blue circle test card with red circle target card). Throughout the assessment the examiner identifies the card according to the dimension being sorted by during that trial (e.g., "Here's a red one, where does it go?"). Completion time for both pre-switch and switch trials is five minutes. Convergent validity was demonstrated as the DCCS and the Block Design subtest of the Wechsler Preschool and Primary Scale of Intelligence, 3rd Edition (WPPSI-III; Wechsler, 2002), a measure of fluid cognition normally highly correlated with EF (e.g., Blair, 2006), were found to be positively correlated for three- to six-year-olds, $r(74) = .69$, $p < .0001$ (Zelazo et al., 2013). The test-retest intraclass correlation coefficient (ICC) for the DCCS is .92 (Zelazo et al., 2013).

The DCCS is easy to administer and involves all three aspects of EF: set-shifting between two rule sets, inhibition to suppress following the previous rule, and working memory to remember relevant rules (Buss & Spencer, 2014). The DCCS has become so connected to the study of EF that researchers have designed studies examining children's performance on the DCCS alone as a proxy for EF performance (e.g., Brooks, Hanauer, Padowska, & Rosman, 2003; Diamond, Carlson, & Beck, 2005; Halford, Bunch, & McCredden, 2007; Kloo, Perner, Kerschhuber, Dabernig, & Aichhorn, 2008; Mack, 2007; Perner & Lang, 2002). Based on the descriptions of types of EF assessment by Garon and associates (2008), in this study the DCCS is classified as a measure of attention set-shifting.

Head Toes Knees Shoulders (HTKS: Ponitz et al., 2009). Children are asked to play a game in which they must do the opposite of the usual rules and the opposite of what the experimenter says. Before the trials, the experimenter tells the child that if the child is told to touch their head, they must touch their toes. If the experimenter says to touch their toes, they must touch their head. If the child passes the head/toes trial, a more advanced trial is administered where knees and shoulders commands are added. The child is instructed to touch their knees if the experimenter says to touch their shoulders or if the experimenter says to touch their knees the child touches their shoulders. The HTKS takes approximately 5-7 minutes to administer and has strong inter-rater reliability (kappa = 0.90; McClelland & Cameron, 2012; Ponitz et al., 2009). McClelland and associates (2014) found the HTKS correlated with the DCCS ($r = 0.56$) and to a measure of working memory ($r = 0.60$; Auditory Working Memory test from the Woodcock-Johnson III; Woodcock et al., 2001). Based on the descriptions of types of EF assessment by Garon and associates (2008), in this study the HTKS is classified as a measure of complex inhibitory-control, as working memory is a moderate component of this measure.

Porteus Maze Test (PMT: Porteus, 1965, Vineland revision). The PMT, originally developed in 1914 to measure planning ability, is a nonverbal assessment of EF (e.g., Gow & Ward, 1982; Krikorian & Bartok, 1998; Tuvblad, May, Jackson, Raine, & Baker, 2017). In the PMT, the participant works through a series of mazes of increasing difficulty, drawing a line from the entrance of the maze to the exit. A script was followed for each maze with instructions to avoid the following: dead ends, lifting the pencil from the paper, and crossing over solid lines. For preschool children, scoring allowances were made for poor motor control (Porteus, 1965). If a mistake is made, or a rule broken, the participant is given a fresh copy of the maze for a second attempt, although a half-point is subtracted from total score (Porteus, 1965). After two failed attempts on a particular maze, the next level maze is given to the child to determine if the ceiling has been reached. If successful on this higher level, an inverted version (same as previous, presented upside-down) of the same higher level is given to determine if success was accidental. If successful, testing continues until ceiling is reached: if unsuccessful, testing stops. In this study, participants started with the maze designed for three-year-olds (Year III) and could advance to one designed for 10-year-olds (Year X). Internal consistency was reported by Krikorian and Bartok (1998; Cronbach's alpha = .81), with completion time between 10 and 15 minutes. Divergent validity was demonstrated as the PMT accounted for a majority of the error variance with intelligence tests (Spreen & Strauss, 1998). Congruent validity (r = .424) was found with the Matching Familiar Figures Test (Kagan, Rosman, Day, Albert, & Phillips, 1964), a measure of impulse control (Gow & Ward, 1982). Based on the descriptions of types of EF assessment by Garon and associates (2008), for the purposes of this study the PMT is classified as a measure of simple inhibitory-control, as working memory is a minimal component of this measure.

Tower of Hanoi (TOH: Klahr, 1978; Simon, 1975). The TOH was administered following the outline described by Bull, Espy, and Senn (2004). This outline used the Welsh, Pennington, and Groisser (1991) version of the TOH, the instructional story from Klahr and Robinson (1981), but simplified the Welsh et al. (1991) version by presenting a single trial for each of six problems, requiring two to seven moves to solve. The TOH consists of three pegs and a “pyramid” of three disks of decreasing size from bottom to top (three disks being optimal for preschool-age children; Welsh et al., 1991). The child moves the disks, one at a time, back and forth across the pegs, until their configuration matches the examiner’s model. The three rules the child follows are: (a) only one disk can move at a time; (b) a bigger disk cannot go on top of a smaller disk; (c) the disks have to stay on the pegs if they are not in the child’s hand. The child is not told the minimum number of moves required for successful completion of each trial and the trials are not timed. Using the Bull et al. (2004) guideline, a problem was discontinued upon completion or if the child made a maximum of 20 moves. Testing was discontinued after two consecutive failures defined as the child refusing to make any moves or failing to make any legal moves. Each problem was given a score based on how many minimal moves were required for solution, for a maximum score of 27. One TOH problem is without counterintuitive moves, two have one counterintuitive move, and three TOH problems include two counterintuitive moves. A counterintuitive move is one where a disk is moved in a direction away from the goal. Test-retest reliability has ranged from .53-.72, depending on the length of the interval between retesting (Bull et al., 2004). Set-shifting was the best predictor of TOH performance, more than inhibition or working memory abilities (Bull et al., 2004), and based on the descriptions of types of EF assessment by Garon and associates (2008), in this study the TOH is classified as a measure of response set-shifting.

Forward-Digit Span. After a practice session, the experimenter repeated digits at the rate of approximately one digit every 2 seconds, starting with a span length of two. If the child recalled the digits in the correct order, the length was increased by one digit.

If the digits were recalled incorrectly, a different digit span of the same length was given. Testing was discontinued if the child failed on the second attempt of any span length, with the maximum span length recorded. Digit span test-retest reliability ranged from .85-.87 (Gray, 2003), and was found to be significantly correlated with the Children's Test of Nonword Repetition (CNRep; Gathercole, Willis, Baddeley, & Emslie, 1994), a measure designed to assess working memory using nonwords (*r* = .524 to *r* = .667; Gathercole, Willis, & Baddeley, 1991). While some researchers classify forward-digit span tasks as a measure of short-term memory and not working memory (e.g., Diamond, 2013), other researchers (e.g., Gropper, Gotlieb, Kronitz, & Tannock, 2014; Klingberg, 2010; Snyder, Kaiser, Warren, & Heller, 2015; Wiebe et al., 2008) have used a forward-digit span task as a measure of preschool-age working memory. For purposes of this study, this task is used as a measure of working memory. For a visual representation of how the face-to-face EF measures are connected to the aspects of EF, see Figure 1.

Set-Shifting	• Response: TOH • Attention: DCCS
Inhibitory Control	• Simple: PMT • Complex: HTKS
Working Memory	• Digit Span

Figure 1. Measures assessing each executive function aspect.

Face-to-face measure of proficiency in mathematics. While there were additional mathematics assessments given in the SUNBEAM study, only one measure, the TEAM, is reported on in this paper, as it provides an assessment of overall mathematics proficiency, with components assessing both numeracy and geometry.

Because of complexity in administration and to maintain inter-rater reliability, only co-project managers administered the TEAM as they were most familiar with the measures and worked on the SUNBEAM study throughout its duration.

Tools for Early Assessment in Math (TEAM; Clements & Sarama, 2011a). The TEAM is a research-based assessment of students' mathematics knowledge and skills using a multi-manipulative, face-to-face interview format. The TEAM assesses algebra, geometry, measurement, data analyses, and numbers and operations, and follows the developmental progression of mathematical learning (Clements & Sarama, 2011a). The TEAM consists of two parts, with Part A focusing on numbers (e.g., number recognition, sequencing, and comparison; verbal and object counting; adding and subtracting, etc.) and Part B focusing on shapes (e.g., shape recognition, composition, and decomposition; construction of shapes and patterns; spatial imagery, etc.). While the TEAM is available in two grade spans (PreK-2 and Grade 3-5), the version used was for children from preschool to second grade. Each part took about 10-20 minutes for administration. Parts A & B were given in a random order, and the two parts were not administered consecutively but had at least another measure presented in between. Concurrent validity (r = .86) for the total test score was established with the Child Math Assessment: Preschool Battery (Klein et al., 2000), another measure of preschool mathematics achievement (Clements, Sarama, & Liu, 2008). For this sample, test-retest reliability after about six months (M = 5.61, SD = 1.12) was .82 (Part A), .54 (Part B).

Teacher measures. Teachers were asked to complete a 15-question demographic questionnaire for information regarding education, experience, and ethnicity, and to complete assessments for each child in the study, including one measure of EF.

Behavior Rating Inventory of Executive Function-Preschool Version (BRIEF-P: Gioia et al., 2003). The BRIEF-P consists of 63 items that measure EF in five nonoverlapping theoretically and empirically supported subscales: Inhibit, Shift, Emotional Control, Working Memory, and Plan/Organize (Gioia et al., 2003). BRIEF-P subscales can be combined to form three broader indices of Inhibitory Self-Control (ISCI: Inhibit + Emotional Control), Flexibility (FI: Shift + Emotional Control), Emergent Metacognition (EMI: Working Memory + Plan/Organize), and an overall score, the Global Executive Composite (GEC: all five subscales summed). The BRIEF-P also includes two additional validity scales (Inconsistency and Negativity). For teacher normative samples, the internal consistency was .90-.97 and the test-retest reliability was .65-.94. For administration, the BRIEF-P requires approximately a fifth-grade reading level and 10-15 minutes to complete (Isquith et al., 2005).

Parent measures. While parents in the SUNBEAM study were asked to complete a packet of assessments regarding their child and the parent-child relationship, for purposes of these analyses only parent demographics were used.

Demographic questionnaire. The demographic questionnaire, completed by parents in the fall (time 1) and spring (time 2), asked 25 questions to collect information regarding parental education, income, and ethnicity.

Analytic Plan

Initial analyses were to clean and validate data, which included identifying outliers, making sure values fell within permissible range, and verifying any potentially questionable values with hard copy of data as needed. To maintain as large of a sample size as possible, pairwise deletion was used to address missing data. Demographic data (i.e., gender, birth date) missing at one time point was identified and included if available at second time point.

Next, correlations were run between demographic variables (population, age, gender), the dependent variables (total TEAM score, TEAM A, TEAM B), and all independent variables (EF scores: DCCS, HTKS, PMT, TOH, forward-digit span, BRIEF-P). The *t* tests and ANOVAs were used to check for differences by gender and between rural and urban populations on EF measures and total TEAM score, TEAM A, and TEAM B. At no point was Time 1 data used to predict Time 2 outcomes (e.g., regressions using Time 1 data did not include Time 2 data, or vice versa), but the longitudinal nature of this study allowed Time 1 results to be compared to Time 2 results.

Research Question 1

How are the various executive function measures and the measure of mathematical performance (numeracy and geometry) related to one another?

To address this question, correlations between independent variables and dependent variables were conducted prior to hierarchical regressions to identify relationships between variables.

Research Question 2

Are there differences in the predictive power of various executive function assessment strategies (single measure, face-to-face panel, face-to-face panel and paper-and-pencil) on preschool-age mathematical performance (numeracy and geometry)?

To explore question 2 a hierarchical regression was conducted with multiple blocks to identify differences in the predictive power of the three strategies. The first block included demographic variables to control for gender, population, and age. The second block added the DCCS to determine how predictive this single EF measure is in predicting mathematical performance. The third block added the panel of face-to-face EF measures (DCCS, TOH, forward digit span, PMT, HTKS). The final block added the paper-and-pencil EF measure (BRIEF-P). By adding these by block, changes in R^2 demonstrated how predictive each strategy is in predicting mathematical performance.

With multiple EF measures included in the hierarchical regression one must be aware of multicollinearity. While initial correlations between variables (both independent and dependent) provide insight into multicollinearity, the tolerance level between variables was reported. The statistic was estimated by subtracting R^2 from one, with R^2 calculated by regressing each independent variable onto the remaining independent variables in the regression. Tolerance levels below 0.20 are evidence of multicollinearity between variables (Hair, Hult, Ringle, & Sarstedt, 2014).

While the DCCS is the measure commonly used as a singular measure of EF, the first two blocks of this hierarchal regression were rerun with all EF measures replacing the DCCS (e.g., Block 2: demographic variables + HTKS, etc.) to determine how well each of the EF measures predicted mathematical performance when used alone.

Research Question 3

How does the predictive power of various executive function assessment strategies (single measure, face-to-face panel, face-to-face panel and paper-and-pencil) change by age, gender, or rural/urban categorization relative to preschool-age mathematical performance (numeracy and geometry)?

To identify differences by age, the sample was split by mean age and the hierarchical regressions from research question one were rerun. As these regressions include gender and location variables, it provided insight into differences in the predictive power of these measures by these variables. And as before, with multiple EF measures included in the hierarchical regression, issues of multicollinearity will be examined as needed.

CHAPTER IV

RESULTS

The following chapter reviews the statistical analyses and results used to answer each of the three research questions. The analyses include descriptive statistics with means and standard deviations. The *t* tests and a three-way ANOVA were run to identify differences between scores from time 1 and time 2, rural and urban samples, male and female scores, and between younger and older children. Correlations were run to identify relationships between independent and dependent variables at time 1 and time 2 for the total sample, the younger children, and for the older children. Hierarchical regressions were used to compare the predictive power of EF assessment strategies for the total sample, and for the younger and older children. Tables were utilized to help depict the results. All analyses were done using SPSS 25.0.

Sample Demographics

One hundred eighteen children (61 girls), ages 39 to 68 months (M = 52.58, SD = 6.35), and their preschool teachers were included in analyses. Teachers and a parent/guardian both completed a paper-and-pencil assessment of child EF, and children responded to a panel of face-to-face EF measures and a measure of math proficiency, with assessments repeated about 6 months later (M = 5.61, SD = 1.12). Children were recruited from state-licensed child care centers operating in rural (four centers; sample size, n = 64) and urban (three centers; sample size, n = 54) areas of a state in the western United States. For a description of child demographics, including gender, and age at Times 1 and 2, by rural and urban samples, see Table 1. For parent demographics, including education level and income, see Table 2. Although statistically significant differences on education level were found between rural and urban populations, income differences between groups were nonsignificant.

Table 1

Child Age and Gender (Time 1/Time 2) by Rural and Urban Samples

	n	Min Age	Max Age	*M* (*SD*)
Rural				
Time 1	64	40	63	51.61 (6.32)
Time 2	55	47	69	58.35 (6.26)
Boys	31/27			
Girls	33/28			
Urban				
Time 1	54	39	68	53.72 (6.24)
Time 2	53	45	72	58.68 (5.96)
Boys	28/28			
Girls	26/25			

Note. Age in months. *M* = mean, *SD* = standard deviation

Analyses were run to identify differences in teacher education level between rural and urban samples. For a description of reported education level, see Table 3. An independent samples *t* test found no statistically significant differences between teacher education levels, simplified from eight levels to two, for rural (n = 10, M = 1.40, SD = .52) and urban (n = 6, M = 1.50, SD = .55) samples, $t(14) = -.37$, $p = .65$. Because the rural sample lost nine child participants between Times 1 and 2 (14.1% of sample), a *t* test was run to compare those without Time 2 data to those that remained. No statistically significant differences were found between these groups on any dependent or independent variables. Prior to combining urban and rural samples, Levene's Test of

Table 2

Parental Income and Education by Rural and Urban Samples

	Rural *M* (*SD*)	Urban *M* (*SD*)	t *Test*	*df*
Income				
Time 1	(*n* = 30)	(*n* = 43)		
	2.23 (.73)	2.49 (.70)	-1.50	71
Time 2	(*n* = 29)	(*n* = 40)		
	2.52 (.63)	2.35 (.80)	.93	67
Education				
Time 1	(*n* = 31)	(*n* = 38)		
	1.48 (.51)	1.79 (.41)	-2.70**	67
Time 2	(*n* = 33)	(*n* = 36)		
	1.36 (.49)	1.81 (.40)	-4.08***	67

Note. Income was simplified from nine levels (1: Less than $10,000; 2: $10,001 to $20,000; 3: $20,001 to $30,000; 4: $30,001 to $40,000; 5: $40,001 to $50,000; 6: $50,001 to $60,000; 7: $60,001 to $70,000; 8: $70,001 to $80,000; 9: $80,001 or more) into three levels (1: $40,000 or less; 2: $40,001 to $80,000; 3: $80,001 or more). Parent education level was recoded from nine levels (1: Some high school; 2: High school diploma/GED; 3: Technical/Vocational school training; 4: Some college; 5: Technical/Vocational certificate; 6: Associate's degree [2-year degree]; 7: Bachelor's degree; 8: Master's degree or equivalent; 9: Ph.D. or other higher education [MD, DDS, etc.]), into two (1: Some high school through Associate's degree; 2: Bachelor's degree or higher).

$^{*}p \leq .05$, $^{**}p \leq .01$, $^{***}p \leq .001$

Table 3

Provider Educational Level by Rural and Urban Samples

	n	High school/ GED	Assoc./ 2-year degree	Technical degree	4-year degree	Master's degree	CDA*
Rural	10	4	0	1	3	1	1
Urban	6	0	2	0	2	1	1

Note. Education level was simplified from eight levels (1: High School; 2: Associates/2-year degree; 3: Technical degree; 4: four-year degree; 5: Master's degree; 6: Ph.D.; 7: Professional degree; 8: Other) to two levels (1: less then Bachelor's degree; 2: equal to or more than four-year degree).

*Responded with an educational attainment of "Other" and wrote in CDA, or Child Development Associate.

Equality of Variances was run indicating that the variances were equal between rural and urban samples for each of the variables tested below.

Differences Between Time 1 and Time 2

A paired samples *t* test was run to look at differences between Time 1 and Time 2 for all dependent and independent variables (see Table 4). When looking at the entire sample (n = 118), statistically significant differences were found between Time 1 and Time 2 for all dependent (TEAM A, TEAM B) and independent (DCCS, TOH, digit span, PMT, HTKS, BRIEF-P) variables. Correlations were run among the demographic variables (gender, age, urbanicity), the two dependent variables (TEAM A, TEAM B), and all independent variables (DCCS, TOH, digit span, PMT, HTKS, BRIEF-P). Table 5 contains correlations for both Time 1 and Time 2, with results split along the diagonal.

Table 4

Paired Samples t *Tests Comparing Time 1 and Time 2 for Entire Sample (n = 118)*

	Time 1 *M* (*SD*)	Time 2 *M* (*SD*)	*t* test
TEAM A	15.16 (9.44)	20.40 (10.30)	-8.78^{***}
TEAM B	8.01 (4.96)	9.92 (4.16)	-4.32^{***}
DCCS	1.73 (0.54)	1.97 (0.55)	-4.33^{***}
TOH	3.93 (4.94)	6.97 (7.74)	-3.95^{***}
Digit Span	3.27 (1.45)	3.80 (1.19)	-4.45^{***}
PMT	5.15 (1.54)	6.62 (1.57)	-10.58^{***}
HTKS	14.25 (12.41)	20.30 (12.93)	-4.53^{***}
BRIEF-P	48.01 (7.92)	46.49 (8.21)	2.10^{*}

Note. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders; BRIEF-P = Behavior Rating Inventory of Executive Function-Preschool Version, Global Composite Score. BRIEF-P is inversely scored, with higher score indicating poorer EF function.
$^{*}p \leq .05$, $^{**}p \leq .01$, $^{***}p \leq .001$

Table 5

Participant Demographic Variables, Numeracy and Geometry Skill, and Face-to-Face Executive Function for Total Sample with Time 1 (n = 118) on Top Diagonal and Time 2 (n = 108) on Bottom Diagonal

Variables	1	2	3	4	5	6	7	8	9	10	11
1. Gender	—	.02	-.00	.02	-.09	.07	.16	-.18	.14	-.11	-.04
2. Age	.01	—	.17	.54***	.36***	.22*	.32***	.41***	.47***	.44***	-.29**
3. Urbanicity	-.00	.03	—	.33***	.04	.14	.04	.23*	.05	.02	-.01
4. TEAM A	.05	.52***	.25**	—	.49***	.41***	.33***	.51***	.46***	.45***	-.29**
5. TEAM B	-.10	.41***	.01	.63***	—	.33***	.18	.31***	.35***	.34***	-.32***
6. DCCS	.02	.27**	.09	.34***	.30**	—	.04	.44***	.25**	.27**	-.28**
7. TOH	.11	.36***	-.01	.43***	.30**	.20*	—	.16	.30***	.14	-.20*
8. Digit Span	-.02	.17	.24*	.32***	.24*	.21*	.07	—	.32***	.34***	-.28**
9. PMT	.20*	.55***	-.07	.47***	.39***	.35***	.29**	.12	—	.27**	-.31***
10. HTKS	.02	.32***	.12	.49***	.53***	.35***	.17	.31***	.40***	—	-.26**
11. BRIEF-P	-.03	-.19	-.01	-.18	-.19	-.24*	.05	-.07	-.28**	-.33***	—

Note. Shaded areas are correlations with TEAM A and TEAM B; lower right quadrant are correlations among EF measures. Gender: Females were coded with 0, males with 1. Urbanicity: Rural was coded 1, Urban was coded 2. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders; BRIEF-P = Behavior Rating Inventory of Executive Function-Preschool Version, Global Composite Score. BRIEF-P is inversely scored, with higher score indicating poorer EF function.
$^{*}p \leq .05$, $^{**}p \leq .01$, $^{***}p \leq .001$

At Time 1, located on the upper diagonal of Table 4, gender did not have statistically significant correlations with other variables, while age had statistically significant correlations with all dependent and independent variables. This relationship was expected as EF and mathematics skills develops rapidly during the preschool years, as has previously been described. Urbanicity, signifying whether the child was from a rural (coded 1) or urban (coded 2) population, correlated with TEAM A, numeracy skills, at $r = .33$ and was statistically significant at $p < .001$, and with the digit span; $r = .23$, $p < .05$. At Time 2, located on the lower diagonal of Table 4, gender had statistically significant correlations with the PMT, a measure of inhibitory control; $r = .20$, $p < .05$. Age had statistically significant correlations with both dependent variables and most independent variables; digit span and BRIEF-P being the exceptions. As at Time 1, urbanicity (rural: coded 1; urban: coded 2) had statistically significant correlations with TEAM A, $r = .25$, $p < .01$, and with the digit span; $r = .24$, $p < .05$.

Question 1

How are the various executive function measures and the measure of mathematical performance (numeracy and geometry) related to one another? To address this question, correlations were run with the two dependent variables (TEAM A, TEAM B), and all independent variables (DCCS, TOH, digit span, PMT, HTKS, BRIEF-P). Table 5 contains both Time 1 and Time 2 correlations, with results split along the diagonal.

At Time 1, TEAM A and TEAM B had statistically significant correlations, indicating the two aspects of mathematics skills are related. While both TEAM A and TEAM B had statistically significant correlations with the EF measures, with the exception of no statistically significant relationship between TEAM B and the TOH, the correlations between the EF measures and TEAM A were more robust. The strongest correlation among EF measures was between the DCCS, a measure of set-shifting but thought to also connect to working memory and inhibitory control, and the digit span, a measure of working memory. With the highest correlation at $r = .44$, multicollinearity does not appear to be an issue among these variables.

At Time 2, TEAM A and TEAM B were more highly correlated that at Time 1. At Time 2 there were statistically significant correlations among all face-to-face EF measures and both TEAM A and TEAM B. At Time 2, the BRIEF-P was no longer statistically significantly correlated with either TEAM A or TEAM B. The two EF measures with the highest correlation were the HTKS and the PMT.

To further explore the relationship between the EF measures and both numeracy and geometry skill, Fisher's *r*-to-*z* transformations (1921) were performed on the correlations between these variables using an online calculator (http://vassarstats.net/tabs_rz.html). *Z* scores are used to ensure the normality of the sample through a variance-stabling transformation. The r-to-z transformation allows for standardized comparisons among EF measures with respect to the dependent variable. The scores (see Table 6) demonstrate that the different EF measures in this study relate to numeracy and geometry in differing ways, and that these relationships change from Time 1 to Time 2. For example, comparing the *z*-scores on the TEAM A, the largest change between Times 1 and 2 was the digit span (Time 1: .56; Time 2: .33), suggesting the influence of working memory changed between the two assessment periods.

Table 6

List of z-Scores Obtained through Fisher's r-to-z Transformations

	TEAM A		TEAM B	
	Time 1	Time 2	Time 1	Time 2
DCCS	.44	.35	.34	.31
TOH	.34	.46	.18	.31
Digit Span	.56	.33	.32	.24
PMT	.50	.51	.37	.41
HTKS	.48	.54	.35	.59
BRIEF-P	-.30	-.18	-.33	-.19

Note. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders. BRIEF-P is reverse coded with higher scores indicating greater problems with EF.

Question 2

Are there differences in the predictive power of various executive function assessment strategies (single measure, face-to-face panel, face-to-face panel and paper-and-pencil) on preschool-age mathematical performance (numeracy and geometry)? Hierarchical regressions were run with multiple blocks to identify differences in the predictive power of the three strategies (see Table 7). For these hierarchical regressions, multicollinearity was not an issue at Time 1 or Time 2 as tolerance levels ranged from 1.00 to .57, well above the 0.20 threshold (Hair et al., 2014).

The first three blocks of variables were next regressed separately on TEAM B, geometry skills, for both Time 1 and Time 2 (see Table 8). As with the previous hierarchical regressions on numeracy skill, multicollinearity was not an issue at Time 1 or Time 2 as tolerance levels again ranged from 1.00 to .57, well above the 0.20 threshold (Hair et al, 2014).

Table 7

Hierarchical Regressions Comparing the Predictive Power of Executive Function Measures and Strategies on Numerical Skills (TEAM A) at Two Time Points

	Time 1		Time 2	
Age: *M* (*SD*)	52.58 (6.35); $n = 118$		58.51 (6.09); $n = 108$	
	β	ΔR^2	β	ΔR^2
Model 1		[a].349***		[a].332***
Age	.50***		.52***	
Urbanicity	.24**		.24*	
Gender	.01		.04	
Model 2		.076***		.033*
Age	.44***		.47***	
Urbanicity	.21**		.22***	
Gender	-.01		.04	
DCCS	.29***		.19*	
Model 3		.117***		.149***
Age	.18*		.24*	
Urbanicity	.22**		.20*	
Gender	.01		-.02	
DCCS	.16*		.05	
TOH	.15*		.24**	
Digit Span	.17*		.11	
PMT	.17*		.17	
HTKS	.20**		.23**	

Note. [a]: Change from no model. Urbanicity: Rural was coded 1, Urban was coded 2. Gender: Females were coded with 0, males with 1. TEAM = Tools for Early Assessment in Math; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders. T1; Model 1: $F(3, 110) = 19.69$, $p < .001$; Model 2: $F(4, 109) = 20.16$, $p < .001$; Model 3: $F(8, 105) = 15.55$, $p < .001$. T2; Model 1: $F(3, 95) = 15.76$, $p < .001$; Model 2: $F(4, 94) = 13.52$, $p < .001$; Model 3: $F(8, 90) = 11.93$, $p < .001$.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

To determine how well each of the EF measures predicted numeracy and geometry skill when used alone, the first two blocks of this hierarchal regression were

Table 8

Hierarchical Regressions Comparing the Predictive Power of Executive Function Measures and Strategies on Geometry Skills (TEAM B) at Two Time Points

	Time 1		Time 2	
Age: *M* (*SD*)	52.58 (6.35); *n* = 118		58.51 (6.09); *n* = 108	
	β	ΔR^2	β	ΔR^2
Model 1		[a].138***		[a].181***
Age	.37***		.42***	
Urbanicity	-.02		-.01	
Gender	-.09		-.10	
Model 2		.070**		.040*
Age	.31***		.36***	
Urbanicity	-.05		-.02	
Gender	-.11		-.10	
DCCS	.27**		.21*	
Model 3		.055		.173***
Age	.14		.16	
Urbanicity	-.03		-.06	
Gender	-.12		-.14	
DCCS	.21*		.05	
TOH	.07		.14	
Digit Span	.03		.07	
PMT	.19		.11	
HTKS	.14		.38***	

Note. [a]: Change from no model. Urbanicity: Rural was coded 1, Urban was coded 2. Gender: Females were coded with 0, males with 1. TEAM = Tools for Early Assessment in Math; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders. T1; Model 1: $F(3, 110) = 5.89$, $p < .001$; Model 2: $F(4, 109) = 7.19$, $p < .001$; Model 3: $F(8, 105) = 4.70$, $p < .001$. T2; Model 1: $F(3, 95) = 7.00$, $p < .001$; Model 2: $F(4, 94) = 6.67$, $p < .001$; Model 3: $F(8, 90) = 7.31$, $p < .001$.

$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

rerun with all EF measures replacing the DCCS (e.g., Block 2: demographic variables + HTKS, etc.). The beta and statistical significance level were included for the EF measure within the model, as well as the variance explained by the model containing that measure. The DCCS, a measure frequently used as a solitary measure of EF and thereby represents that analytical approach, was included in the table as a comparison (see Table 9 for numeracy skill, Table 10 for geometry skill).

Table 9

Hierarchical Regressions Comparing the Predictive Power of Individual Executive Function Measures for Numeracy Skill (TEAM A) at Two Time Points

	Time 1 (n = 118)			Time 2 (n = 108)		
	β	Sig.	R^2	β	Sig.	R^2
DCCS	.29	.000	.425	.19	.029	.365
TOH	.18	.024	.378	.28	.002	.397
Digit Span	.33	.000	.433	.19	.032	.364
PMT	.28	.001	.408	.30	.004	.390
HTKS	.29	.001	.417	.33	.000	.428

Note. The standardized regression coefficients (betas) and statistical significance levels reported are from hierarchal regressions containing the same variables (age, gender, urbanicity). R-squares are model fit for the model containing that singular measure of executive function. TEAM = Tools for Early Assessment in Math; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders.

Results from these hierarchical regressions (see Table 8) show that for Time 1, the measure with the greatest beta (β = .33, p < .001) explaining the largest amount of variance (R^2 = .43) in numerical performance was the digit span. However, at Time 2 the digit span had one of the lowest reported betas (β = .19, p < .05) and the lowest R-squared (R^2 = .36). The measure that explained the greatest variance in numeracy skill (R^2 = .43) at Time 2 was the HTKS (β = .33, p < .001).

Hierarchical regressions repeated for geometry skills showed fewer statistically significant predictors, with TOH and digit span being not statistically significant at both time points (see Table 10). While all measures became better solitary predictors of geometry skill at Time 2 compared to their predictability at Time 1, the measure with the most change from Time 1 to Time 2 was the HTKS (Time 1: $\beta = .22$, $p < .05$, $R^2 = .175$; Time 2: $\beta = .45$, $p < .001$, $R^2 = .358$).

Table 10

Hierarchical Regressions Comparing the Predictive Power of Individual Executive Function Measures for Geometry (TEAM B) at Two Time Points

	Time 1			Time 2		
	β	Sig.	R^2	β	Sig.	R^2
DCCS	.27	.002	.209	.21	.029	.221
TOH	.09	.328	.146	.18	.070	.209
Digit Span	.20	.052	.168	.19	.055	.212
PMT	.26	.009	.190	.27	.016	.230
HTKS	.22	.030	.175	.45	.000	.358

Note. The betas and significance levels reported are from hierarchal regressions containing the same control variables (age, gender, urbanicity). R-squares are model fit for the model containing that singular measure of executive function. TEAM = Tools for Early Assessment in Math; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders.

Question 3

How does the predictive power of various executive function assessment strategies (single measure, face-to-face panel, face-to-face panel and paper-and-pencil) change by age, gender, or rural/urban categorization relative to preschool-age mathematical performance (numeracy and geometry)? To answer this question, first group means and standard deviations were figured for age groups, gender, and rural/urban categorization. A three-way ANOVA was run to test for main effects and interactions with regard to age, gender, and urbanicity. Then hierarchical regressions were run to explore how EF demographic variables differ in predicting both numeracy and geometry abilities.

Differences Between Younger and Older Samples

Because of the rapid development occurring during the preschool years, and in an attempt to identify differences in the relationships between EF and mathematics variables occurring by age, urban and rural samples were combined and split at the mean age (52.58 months). For a demographic description of these two samples see Table 11. For the means and standard deviations for younger and older children on both dependent and independent variables at Time 1 and Time 2, see Table 12. To examine differences between younger and older boys and girls, the sample was split by gender, with girls' means and standard deviations in Table 13, and boys' means and standard deviations in Table 14.

Table 11

Child Age, Gender, and Rural/Urban Categorization by Younger and Older Samples

	Age					
	n	Min	Max	*M* (*SD*)	Boys/Girls	Rural/Urban
Younger					28/30	37/21
Time 1	58	39	52	47.26 (3.74)		
Time 2	50	45	59	53.22 (3.75)		
Older					29/31	27/33
Time 1	60	53	68	57.72 (3.42)		
Time 2	58	58	72	63.07 (3.43)		

Note. Age in months.

Table 12

Means and Standard Deviations for Younger and Older Children on Mathematics and Executive Function Measures at Times 1 and 2

	Younger Children		Older Children	
	n	*M* (*SD*)	*n*	*M* (*SD*)
TEAM A				
Time 1	57	10.54 (7.11)	60	18.96 (9.36)
Time 2	46	15.37 (7.93)	55	24.60 (10.23)
TEAM B				
Time 1	57	6.16 (5.38)	60	8.99 (3.91)
Time 2	45	8.47 (4.12)	55	11.11 (3.84)
DCCS				
Time 1	57	1.63 (0.62)	60	1.83 (0.42)
Time 2	48	1.79 (0.58)	56	2.13 (0.47)
TOH				
Time 1	57	2.67 (3.28)	60	4.82 (5.67)
Time 2	49	4.80 (3.91)	56	8.88 (9.60)
Digit Span				
Time 1	56	2.61 (1.57)	59	3.85 (0.83)
Time 2	48	3.58 (1.35)	56	3.95 (1.03)
PMT				
Time 1	57	4.39 (1.24)	60	5.82 (1.46)
Time 2	49	5.90 (1.54)	55	7.26 (1.30)
HTKS				
Time 1	56	8.73 (11.09)	59	18.10 (12.42)
Time 2	47	16.83 (12.87)	56	22.89 (12.55)

Note. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders.

Table 13

Means and Standard Deviations for Girls on Mathematics and Executive Function Measures at Times 1 and 2

	Younger Girls		Older Girls	
	n	*M* (*SD*)	*n*	*M* (*SD*)
TEAM A				
Time 1	30	10.77 (6.02)	31	18.40 (7.42)
Time 2	23	15.98 (6.64)	28	23.20 (8.01)
TEAM B				
Time 1	29	7.12 (6.71)	31	8.85 (3.07)
Time 2	23	8.85 (4.23)	28	11.50 (3.37)
DCCS				
Time 1	29	1.55 (0.63)	31	1.84 (0.45)
Time 2	26	1.77 (0.59)	29	2.14 (0.58)
TOH				
Time 1	29	2.21 (2.26)	31	3.77 (4.17)
Time 2	26	4.96 (4.24)	29	7.31 (8.57)
Digit Span				
Time 1	28	2.96 (1.43)	30	3.97 (1.00)
Time 2	26	3.62 (1.20)	29	3.97 (1.27)
PMT				
Time 1	29	4.21 (1.32)	31	5.57 (1.38)
Time 2	26	5.73 (1.48)	29	6.86 (1.32)
HTKS				
Time 1	28	9.04 (12.26)	30	20.33 (10.96)
Time 2	25	17.56 (12.41)	29	21.79 (13.45)

Note. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders.

Table 14

Means and Standard Deviations for Boys on Mathematics and Executive Function Measures at Times 1 and 2

	Younger Boys		Older Boys	
	n	*M* (*SD*)	*n*	*M* (*SD*)
TEAM A				
Time 1	27	10.30 (8.26)	29	19.55 (11.17)
Time 2	23	14.76 (9.15)	27	26.06 (12.10)
TEAM B				
Time 1	28	5.16 (3.39)	29	9.14 (4.69)
Time 2	23	8.07 (4.07)	27	10.70 (4.30)
DCCS				
Time 1	28	1.71 (0.60)	29	1.83 (0.38)
Time 2	22	1.82 (0.59)	27	2.11 (0.32)
TOH				
Time 1	28	3.14 (4.06)	29	5.93 (6.82)
Time 2	23	4.61 (3.58)	27	10.56 (10.49)
Digit Span				
Time 1	28	2.25 (1.65)	29	3.72 (0.59)
Time 2	22	3.55 (1.54)	27	3.93 (0.73)
PMT				
Time 1	28	4.57 (1.15)	29	6.09 (1.52)
Time 2	23	6.09 (1.61)	26	7.69 (1.15)
HTKS				
Time 1	28	8.43 (10.00)	29	15.79 (13.58)
Time 2	22	16.00 (13.62)	27	24.07 (11.64)

Note. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders.

To further explore how the relationships between the dependent and independent variables differed for the younger and older children, correlations were repeated (see Table 15 for younger children and Table 16 for older children). For the youngest children at Time 1, located on the upper diagonal of Table 15, gender did not statistically significantly correlate with other variables. Age was correlated with TEAM A for these children, but not TEAM B. Age was related to the HTKS, but not to other face-to-face EF measure at Time 1 for the youngest children. Urbanicity was correlated with TEAM A and no other variable. TEAM A and TEAM B were correlated, suggesting numeracy and geometry skills were somewhat connected for the youngest children at Time 1. TEAM B was statistically significantly correlated with the following face-to-face EF measures: DCCS, TOH, digit span, and PMT, but not the HTKS. The strongest correlation among EF measures was between the DCCS, a measure of set-shifting, and the digit span, a measure of working memory. Correlations for this group suggest that multicollinearity does not appear to be an issue among these variables

For younger children at Time 2, located on the lower diagonal of Table 15, gender did not have statistically significant correlations with other variables. Unlike the correlations for the total sample, age had statistically significant correlations with the TEAM B, digit span, and PMT. However, age was correlated with more variables at Time 2 than at Time 1. At Time 2 the only variable with which urbanicity had a statistically significant correlation was the digit span. TEAM A and TEAM B were significantly correlated, indicating the two aspects of mathematics skills are interconnected for the youngest children at Time 2. TEAM A had statistically significant correlations with the DCCS, digit span, PMT, and HTKS, but not with the TOH.

Table 15

Correlations Between Participant Demographic Variables, TEAM A and B, and Face-to-Face Executive Function Measures for Younger Sample with Time 1 (n = 58; age in months: M = 47.26, SD = 3.74) on Top Diagonal and Time 2 (n = 50; age in months: M = 53.22, SD = 3.75) on Bottom Diagonal.

Variables	1	2	3	4	5	6	7	8	9	10
1. Gender	—	.05	-.01	-.03	-.18	.13	.14	-.23	.15	-.03
2. Age	-.00	—	.04	.44***	.22	.13	.25	.21	.23	.28*
3. Urbanicity	-.01	.15	—	.31*	-.05	.10	.00	.22	-.03	-.09
4. TEAM A	-.08	.20	.22	—	.37**	.57***	.07	.58***	.26	.43***
5. TEAM B	-.10	.32*	-.10	.73**	—	.33*	.27*	.27*	.27*	.20
6. DCCS	.04	.03	.09	.40**	.27	—	.17	.46***	.24	.41**
7. TOH	-.05	.26	-.14	.21	.14	.32*	—	.14	.10	-.03
8. Digit Span	-.03	.31*	.17	.31*	.20	.27	.26	—	.21	.29*
9. PMT	.12	.41**	-.19	.33*	.31*	.30*	.31*	.23	—	.11
10. HTKS	-.06	.10	-.31*	.45**	.40**	.40**	.15	.44**	.39**	—

Note. Shaded areas are correlations with TEAM A and TEAM B; lower right quadrant are correlations among EF measures. Gender: Females were coded with 0, males with 1. Urbanicity: Rural was coded 1, Urban was coded 2. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

Table 16

Correlations Between Participant Demographic Variables, TEAM A and B, and Face-to-Face Executive Function Measures for Older Urbanicity with Time 1 (n = 60; age in months: M = 57.72, SD = 3.42) on Top Diagonal and Time 2 (n = 58; age in months: M = 63.07, SD = 3.43) on Bottom Diagonal.

Variables	1	2	3	4	5	6	7	8	9	10
1. Gender	—	.02	.00	.06	.04	-.01	.19	-.15	.18	-.18
2. Age	.02	—	-.06	.25	.23	.09	.25	-.16	.11	.24
3. Urbanicity	.00	-.23	—	.26*	.04	.12	.00	.09	-.06	-.03
4. TEAM A	.14	.40**	.15	—	.50***	.20	.34**	.22	.34**	.29*
5. TEAM B	-.11	.25	-.03	.49***	—	.22	.03	.08	.26*	.34**
6. DCCS	-.03	.05	-.01	.11	.17	—	-.14	.27*	.13	.01
7. TOH	.17	.30*	-.03	.40**	.29*	.07	—	.03	.28*	.10
8. Digit Span	-.02	-.18	.28*	.27*	.22	.05	-.06	—	.05	.12
9. PMT	.32*	.32*	-.15	.38**	.28*	.19	.21	-.17	—	.10
10. HTKS	.09	.35**	-.11	.43***	.56***	.22	.12	.11	.29*	—

Note. Shaded areas are correlations with TEAM A and TEAM B; lower right quadrant are correlations among EF measures. Gender: Females were coded with 0, males with 1. Urbanicity: Rural was coded 1, Urban was coded 2. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

TEAM B had fewer statistically significant EF connections for the younger children at Time 2, only correlating with the PMT and the HTKS. The strongest correlation among EF measures was between the HTKS, a measure of complex inhibitory control, and the digit span, a measure of working memory. With the highest correlation at $r = .44$, multicollinearity does not appear to be an issue among these variables.

At Time 1 for the older children (see Table 16), located on the upper diagonal, gender and age did not have statistically significant correlations with any variables. For older children at Time 1, urbanicity had a statistically significant correlation with TEAM A and no other variable. TEAM A and TEAM B were again correlated, although not as strongly as at Time 2 for younger children. TEAM A also correlated with three of the face-to-face EF measures, TOH, PMT, and HTKS. TEAM B correlated with two of the face-to-face EF measures, PMT and HTKS, two measures of inhibitory control. Based on the strength of these correlations, multicollinearity was not an issue among these variables.

For the older children at Time 2, gender was correlated with the PMT, the first time that gender had a statistically significant correlation. As with Time 2 for the younger children (see Table 15), age again correlated with TEAM A, but also with TOH, PMT, and HTKS. Urbanicity correlated with digit span and TEAM A and TEAM B were again correlated. TEAM A correlated with four face-to-face EF measures at Time 2: TOH, digit span, PMT, and HTKS. TEAM B had a statistically significant correlation with TOH, PMT, and the HTKS. The only statistically significant correlation between face-to-face EF measures was between PMT and HTKS and at a level that did not suggest multicollinearity.

To explore the relationships between the EF measures and both TEAM A and TEAM B in more depth, Fisher's *r*-to-*z* transformations (1921) were performed on the correlations between EF measures and TEAM A and EF measures and TEAM B for both the younger and older children using an online calculator (http://vassarstats.net/tabs_rz.html). The *z*-scores ensure the normality of the sample through a variance-stabling transformation. The standardized scores (see Table 17) demonstrate the standardized relationship of the separate EF measures to numeracy and geometry, and how these relationships changed from Time 1 to Time 2.

Table 17

List of z-Scores Obtained through Fisher's r-to-z Transformations for Younger and Older Children

	TEAM A		TEAM B	
	Time 1	Time 2	Time 1	Time 2
Younger				
DCCS	.65	.42	.34	.28
TOH	.07	.21	.28	.14
Digit Span	.66	.32	.28	.20
PMT	.27	.34	.28	.32
HTKS	.46	.48	.20	.42
Older				
DCCS	.20	.11	.22	.17
TOH	.35	.42	.03	.30
Digit Span	.22	.28	.08	.22
PMT	.35	.40	.27	.29
HTKS	.30	.46	.35	.63

Note. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders.

Differences by Gender

To look for distribution of scores by gender, first means and standard deviations on mathematics and EF measures were reported for girls and boys (see Table 18), then

Table 18

Means and Standard Deviations for Girls and Boys on Mathematics and Executive Function Measures at Time 1 and Time 2

	Girls		Boys	
	n	*M* (*SD*)	*n*	*M* (*SD*)
TEAM A				
Time 1	61	14.65 (7.74)	56	15.09 (10.84)
Time 2	51	19.94 (8.20)	50	20.86 (12.15)
TEAM B				
Time 1	60	8.02 (5.18)	57	7.18 (4.54)
Time 2	51	10.30 (3.97)	49	9.52 (4.36)
DCCS				
Time 1	60	1.70 (0.56)	57	1.77 (0.50)
Time 2	55	1.96 (0.61)	49	1.98 (0.48)
TOH				
Time 1	60	3.02 (3.45)	57	4.56 (5.76)
Time 2	55	6.20 (6.91)	50	7.82 (8.55)
Digit Span				
Time 1	58	3.48 (1.31)	57	3.00 (1.43)
Time 2	55	3.80 (1.24)	49	3.76 (1.16)
PMT				
Time 1	60	4.91 (1.51)	57	5.34 (1.54)
Time 2	55	6.33 (1.50)	49	6.94 (1.59)
HTKS				
Time 1	58	14.88 (12.84)	57	12.18 (12.42)
Time 2	54	19.83 (13.03)	49	20.45 (13.08)

Note. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders.

for younger (see Table 19) and older (see Table 20) girls and boys. The results listed on the three tables provide support for analyses examining the influence of gender on the dependent (TEAM A, TEAM B) and independent (DCCS, TOH, digit span, PMT, HTKS) variables.

Table 19

Means and Standard Deviations for Younger Girls and Boys on Mathematics and Executive Function Measures at Time 1 and Time 2

	Younger Girls		Younger Boys	
	n	*M* (*SD*)	*n*	*M* (*SD*)
TEAM A				
Time 1	30	10.77 (6.02)	27	10.30 (8.26)
Time 2	23	15.98 (6.64)	23	14.76 (9.15)
TEAM B				
Time 1	29	7.12 (6.71)	28	5.16 (3.39)
Time 2	23	8.85 (4.23)	23	8.07 (4.07)
DCCS				
Time 1	29	1.55 (0.63)	28	1.71 (0.60)
Time 2	26	1.77 (0.59)	22	1.82 (0.59)
TOH				
Time 1	29	2.21 (2.26)	28	3.14 (4.06)
Time 2	26	4.96 (4.24)	23	4.61 (3.58)
Digit Span				
Time 1	28	2.96 (1.43)	28	2.25 (1.65)
Time 2	26	3.62 (1.20)	22	3.55 (1.54)
PMT				
Time 1	29	4.21 (1.32)	28	4.57 (1.15)
Time 2	26	5.73 (1.48)	23	6.09 (1.61)
HTKS				
Time 1	28	9.04 (12.26)	28	8.43 (10.00)
Time 2	25	17.56 (12.41)	22	16.00 (13.62)

Note. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders.

Table 20

Means and Standard Deviations for Older Girls and Boys on Mathematics and Executive Function Measures at Time 1 and Time 2

	Older Girls		Older Boys	
	n	*M* (*SD*)	*n*	*M* (*SD*)
TEAM A				
Time 1	31	18.40 (7.42)	29	19.55 (11.17)
Time 2	28	23.20 (8.01)	27	26.06 (12.10)
TEAM B				
Time 1	31	8.85 (3.07)	29	9.14 (4.69)
Time 2	28	11.50 (3.37)	27	10.70 (4.30)
DCCS				
Time 1	31	1.84 (0.45)	29	1.83 (0.38)
Time 2	29	2.14 (0.58)	27	2.11 (0.32)
TOH				
Time 1	31	3.77 (4.17)	29	5.93 (6.82)
Time 2	29	7.31 (8.57)	27	10.56 (10.49)
Digit Span				
Time 1	30	3.97 (1.00)	29	3.72 (0.59)
Time 2	29	3.97 (1.27)	27	3.93 (0.73)
PMT				
Time 1	31	5.57 (1.38)	29	6.09 (1.52)
Time 2	29	6.86 (1.32)	26	7.69 (1.15)
HTKS				
Time 1	30	20.33 (10.96)	29	15.79 (13.58)
Time 2	29	21.79 (13.45)	27	24.07 (11.64)

Note. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders.

Differences Between Rural and Urban Samples

As with previous samples, first the means and standard deviations were presented to see the distribution of scores for rural and urban samples (see Table 21).

Table 21

Means and Standard Deviations for Rural and Urban Samples on Mathematics and Executive Function Measures at Time 1 and Time 2

	Rural Sample		Urban Sample	
	n	*M* (*SD*)	*n*	*M* (*SD*)
TEAM A				
Time 1	63	12.05 (8.56)	54	18.14 (9.15)
Time 2	52	17.90 (10.41)	49	23.04 (9.60)
TEAM B				
Time 1	63	7.43 (5.35)	54	7.82 (4.30)
Time 2	51	9.89 (4.47)	49	9.95 (3.86)
DCCS				
Time 1	63	1.67 (0.54)	54	1.81 (0.52)
Time 2	51	1.92 (0.52)	53	2.02 (0.57)
TOH				
Time 1	63	3.59 (3.84)	54	3.98 (5.69)
Time 2	52	7.02 (7.48)	53	6.92 (8.06)
Digit Span				
Time 1	61	2.95 (1.48)	54	3.57 (1.21)
Time 2	51	3.49 (1.33)	53	4.06 (0.99)
PMT				
Time 1	63	5.06 (1.40)	54	5.19 (1.69)
Time 2	52	6.73 (1.51)	52	6.50 (1.63)
HTKS				
Time 1	61	13.36 (13.03)	54	13.74 (12.32)
Time 2	50	18.50 (13.32)	53	21.66 (12.62)

Note. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders.

To look for statistically significant changes on the variables between Time 1 and Time 2, paired samples *t* tests were run for the rural and urban samples. For both the rural and urban (see Table 22) samples, statistically significant differences were found between Time 1 and Time 2 for all dependent (TEAM A, TEAM B) and independent

Table 22

Paired Samples t *Tests Comparing Time 1 and Time 2 for Rural and Urban Children*

	Time 1 *M* (*SD*)	Time 2 *M* (*SD*)	t *Test*	*df*
Rural				
TEAM A	12.10 (8.76)	17.90 (10.41)	-7.20***	51
TEAM B	7.92 (5.64)	9.89 (4.47)	-2.81**	50
DCCS	1.65 (0.56)	1.92 (0.52)	-3.25**	50
TOH	3.81 (4.05)	7.02 (7.48)	-3.12**	51
Digit Span	2.94 (1.61)	3.52 (1.33)	-2.87**	49
PMT	5.10 (1.35)	6.73 (1.51)	-9.92***	51
HTKS	14.73 (12.49)	18.84 (13.24)	-2.50*	48
Urban				
TEAM A	18.42 (9.12)	23.04 (9.60)	-5.25***	48
TEAM B	8.09 (4.20)	9.95 (3.86)	-3.42***	48
DCCS	1.81 (0.52)	2.02 (0.57)	-2.84**	52
TOH	4.06 (5.71)	6.92 (8.06)	-2.49*	52
Digit Span	3.58 (1.22)	4.06 (0.99)	-3.68***	52
PMT	5.21 (1.72)	6.50 (1.63)	-5.84***	51
HTKS	13.81 (12.43)	21.66 (12.61)	-3.81***	52

Note. TEAM = Tools for Early Assessment in Math, TEAM A: Numeracy, TEAM B: Geometry; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

(DCCS, TOH, digit span, PMT, HTKS) variables. Rural children's TEAM A scores improved more between Times 1 and 2, while urban children improved more on the TEAM B. For the face-to-face EF measures, rural children showed more improvement between Times 1 and 2 on the DCCS, TOH, and PMT, while urban children showed more improvement between these time points on the digit span and the HTKS.

Demographic Differences and Assessment Strategies

With difference distributions of mean scores between younger and older children shown above, a series of three-way ANOVAs were run to identify differences by age, gender, and urbanicity for EF measures and TEAMs A and B (see Table 23). While there were no statistically significant three-way interactions, Table 24 shows statistically significant main effects and two-way interactions.

Table 23

Significant Main Effects (F and p) for Three-way Analyses of Variance (Age, Gender, Urbanicity) for Time 1 and Time 2 (1 df)

Time 1			
Main Effects	Age	Gender	Urbanicity
TEAM A	24.71^{***}	ns	10.00^{**}
TEAM B	10.69^{***}	ns	ns
DCCS	ns	ns	ns
TOH	5.94^{*}	ns	ns
Digit Span	24.06^{***}	ns	ns
PMT	31.71^{***}	ns	ns
HTKS	18.19^{***}	ns	ns
Time 2			
Main Effects	Age	Gender	Urbanicity
TEAM A	20.52^{***}	ns	10.00^{**}
TEAM B	11.11^{***}	ns	ns
DCCS	8.95^{**}	ns	ns
TOH	8.28^{**}	ns	ns
Digit Span	ns	ns	4.60^{*}
PMT	26.78^{***}	4.44^{*}	ns
HTKS	5.30^{*}	ns	ns

$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

Table 24

Significant 2-way Interactions from Three-way Analyses of Variance (Age, Gender, Urbanicity) for Time 1 and Time 2 (1 df)

2-way Interaction	Sums-Squares	Mean-Squares	*F*
Time 1			
DCCS			
Urbanicity * Gender	1.35	1.35	5.03^*
Time 2			
HTKS			
Urbanicity * Gender	689.32	689.32	4.56^*
Urbanicity * Age	691.55	691.55	4.57^*

$^*p < .05$

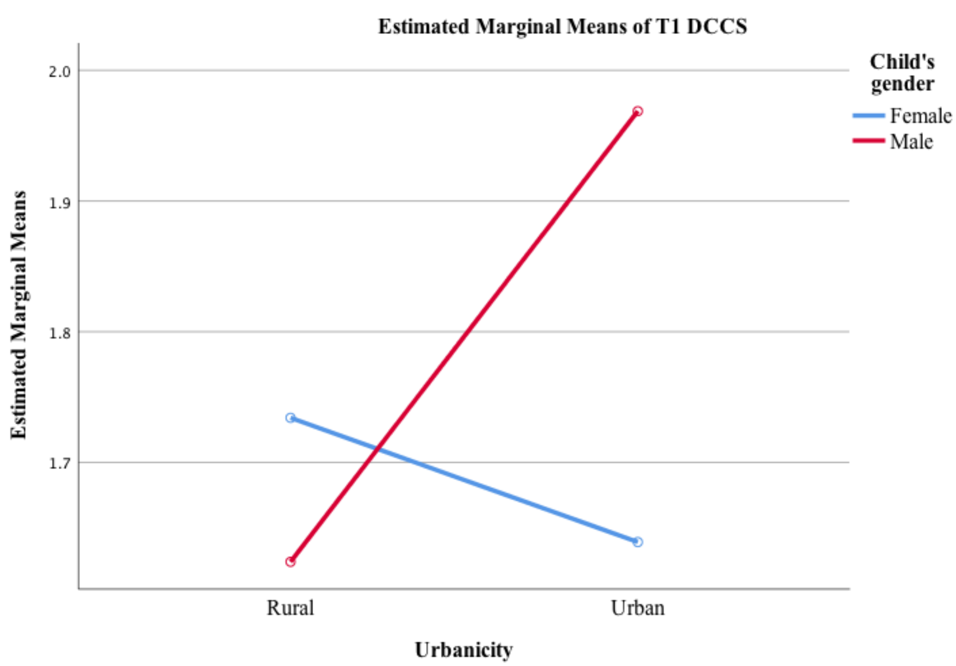

Figure 2. Two-way interaction of Urbanicity * Gender for DCCS at Time 1.

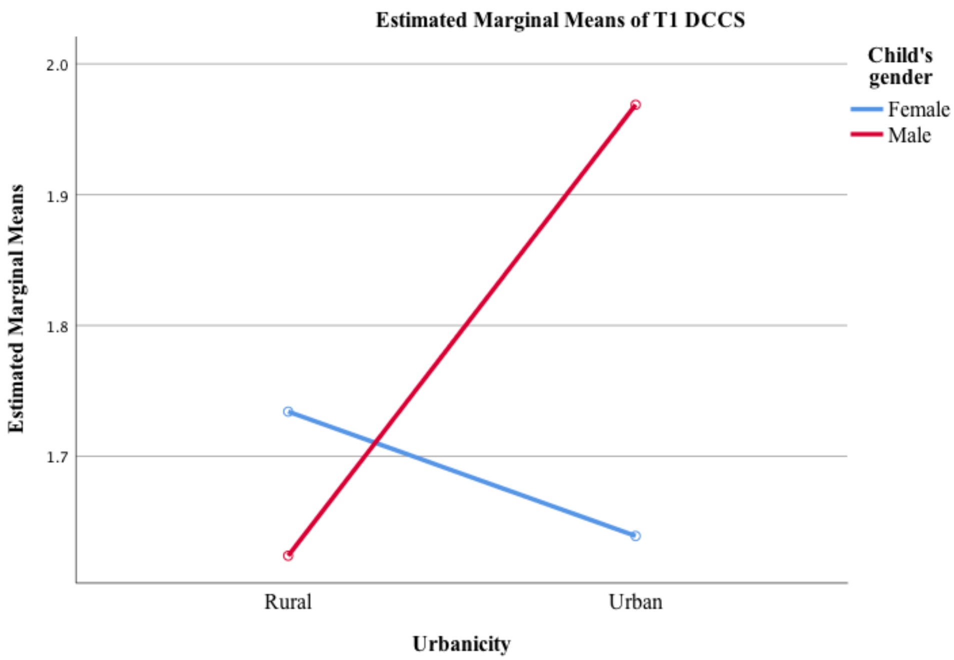

Figure 3. Two-way interaction of Urbanicity * Gender for HTKS at Time 2.

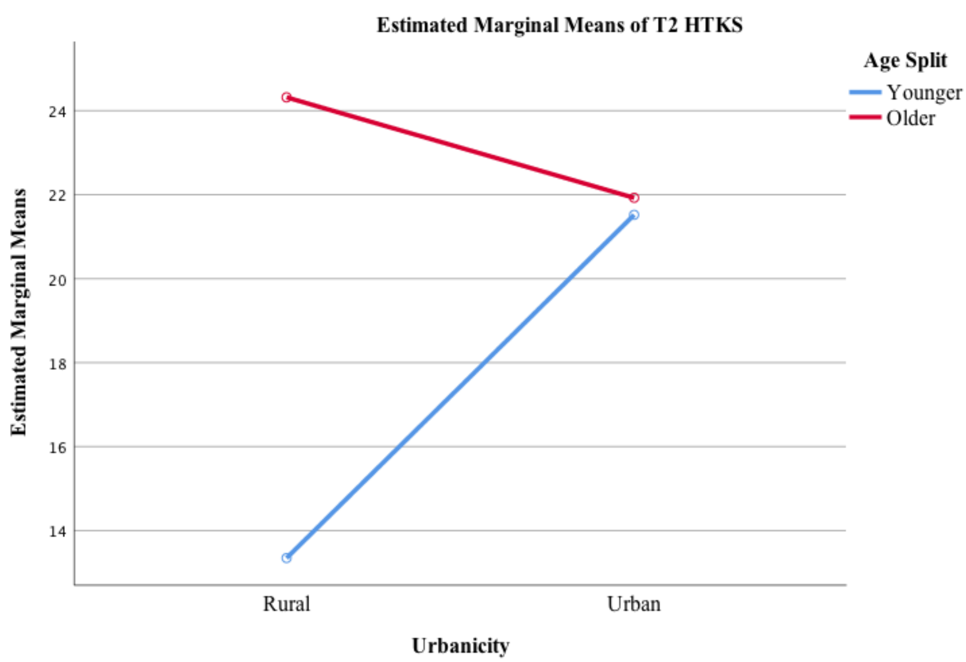

Figure 4. Two-way interaction of Urbanicity * Age for HTKS at Time 2.

To examine the influence of these differences (age, gender, and urbanicity) on the predictive power of the various EF assessment strategies (single measure, face-to-face panel), the following hierarchical regressions were rerun on both the younger and older samples (mean age = 52.58 months). The first block again included demographic variables (age, gender, urbanicity) while the second block added the DCCS to determine how predictive this single EF measure is in predicting mathematical performance. The third block added the panel of face-to-face EF measures (DCCS, TOH, digit span, PMT, HTKS). Because of its nonsignificance, the BRIEF-P was again excluded from analyses.

The first three blocks of variables, as outlined above, were regressed on TEAM A for the younger and older children at both Time 1 and Time 2 (see Table 25), for a total of four hierarchical regressions on TEAM A (Younger: Time 1 and Time 2; Older: Time 1 and Time 2). Among the demographic variables in block 1, both age and urbanicity were statistically significant during at least one time point, while gender was not at any of the time points. Model 1, consisting of demographic variables, was statistically significant for three out of four groups; the exception being the younger sample at Time 2. When the DCCS was included in block 2, the ΔR^2 was statistically significant, but only for the younger children.

Regressing block 3 resulted in a statistically significant ΔR^2, but only for the older children. For the younger children, at Time 1 both the DCCS and digit span were statistically significant predictors of TEAM A, while at Time 2 no face-to-face EF measure was statistically significant. For older children, at Time 1 there were no statistically significant predictors of numeracy skill, while at Time 2 the TOH, digit span,

Table 25

Hierarchical Regressions Comparing the Predictive Power of Executive Function Measures and Strategies on Numerical Skills (TEAM A) for Four Non-Independent Groups

	Younger						Older					
	T1 (n = 58)			T2 (n = 50)			T1 (n = 60)			T2 (n = 58)		
Age: *M* (*SD*)	47.26 (3.74)			53.22 (3.75)			57.72 (3.42)			63.07 (3.43)		
	β	Sig.	ΔR^2	β	Sig.	ΔR^2	β	Sig.	ΔR^2	β	Sig.	ΔR^2
Model 1			[a].283***			[a].109			[a].134*			[a].235**
Age	.43	.001		.23	.129		.25	.050		.45	.001	
Urbanicity	.29	.017		.26	.097		.26	.042		.25	.051	
Gender	-.05	.654		-.07	.621		.06	.660		.13	.296	
Model 2			.251***			.141**			.023			.008
Age	.37	.000		.22	.127		.24	.063		.45	.001	
Urbanicity	.24	.016		.22	.124		.24	.060		.25	.052	
Gender	-.12	.229		-.09	.517		.06	.645		.13	.289	
DCCS	.51	.000		.38	.010		.15	.232		.09	.471	
Model 3			.083			.076			.219**			.273***
Age	.30	.004		.11	.521		.13	.293		.25	.049	
Urbanicity	.22	.027		.18	.255		.25	.030		.20	.078	
Gender	-.02	.851		-.09	.532		.04	.768		-.01	.905	
DCCS	.33	.007		.23	.158		.12	.332		-.04	.725	
TOH	-.09	.339		.03	.829		.23	.072		.28	.015	
Digit Span	.28	.021		.05	.745		.15	.241		.30	.011	
PMT	.06	.551		.16	.375		.23	.062		.26	.037	
HTKS	.14	.209		.19	.306		.21	.079		.24	.052	

Note. [a]: Change from no model. Urbanicity: Rural = 1, Urban = 2. Gender: Females coded 0, males 1. TEAM = Tools for Early Assessment in Math; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders. Younger: T1; Model 1: $F(3, 51) = 6.70$, $p < .001$; Model 2: $F(4, 50) = 14.28$, $p < .001$; Model 3: $F(8, 46) = 9.25$, $p < .001$. T2; Model 1: $F(3, 40) = 1.63$, $p = .20$; Model 2: $F(4, 39) = 3.24$, $p < .05$; Model 3: $F(8, 35) = 2.11$, $p = .06$. Older: T1; Model 1: $F(3, 55) = 2.84$, $p < .05$; Model 2: $F(4, 54) = 2.52$, $p = .05$; Model 3: $F(8, 50) = 3.77$, $p < .01$. T2; Model 1: $F(3, 50) = 5.13$, $p < .01$; Model 2: $F(4, 49) = 3.94$, $p < .01$; Model 3: $F(8, 45) = 6.01$, $p < .001$.

$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

Table 26

Hierarchical Regressions Comparing the Predictive Power of Executive Function Measures and Strategies on Geometry Skills (TEAM B) for Four Non-Independent Groups

	Younger						Older					
	T1 (*n* = 58)			T2 (*n* = 50)			T1 (*n* = 60)			T2 (*n* = 58)		
Age: *M* (*SD*)	47.26 (3.74)			53.22 (3.75)			57.72 (3.42)			63.07 (3.43)		
	β	Sig.	ΔR^2	β	Sig.	ΔR^2	β	Sig.	ΔR^2	β	Sig.	ΔR^2
Model 1			[a].090			[a].113			[a].053			[a].073
Age	.23	.089		.31	.045		.23	.092		.25	.075	
Urbanicity	-.07	.626		-.05	.741		.04	.771		.03	.861	
Gender	-.20	.147		-.10	.526		.03	.811		-.11	.423	
Model 2			.114**			.075			.038			.024
Age	.19	.139		.30	.047		.21	.116		.25	.085	
Urbanicity	-.10	.436		-.08	.601		.01	.914		.02	.864	
Gender	-.24	.065		-.11	.463		.04	.791		-.11	.441	
DCCS	.35	.010		.28	.065		.20	.137		.15	.262	
Model 3			.081			.110			.130			.375***
Age	.10	.498		.29	.095		.14	.301		-.03	.845	
Urbanicity	-.08	.558		-.19	.241		.04	.766		-.00	.971	
Gender	-.29	.042		-.08	.572		.08	.576		-.26	.032	
DCCS	.26	.100		.17	.320		.15	.269		-.01	.938	
TOH	.22	.103		-.06	.702		-.09	.547		.25	.035	
Digit Span	-.00	.984		-.06	.722		.03	.846		.21	.082	
PMT	.21	.132		-.01	.961		.20	.140		.22	.092	
HTKS	.03	.834		.40	.041		.30	.028		.48	.000	

Note. [a]: Change from no model. Urbanicity: Rural = 1, Urban = 2. Gender: Females coded 0, males 1. TEAM = Tools for Early Assessment in Math; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders. Younger: T1; Model 1: $F(3, 51) = 1.69$, $p = .18$; Model 2: $F(4, 50) = 3.21$, $p < .05$; Model 3: $F(8, 46) = 2.29$, $p < .05$. T2; Model 1: $F(3, 40) = 1.70$, $p = .18$; Model 2: $F(4, 39) = 2.26$, $p = .08$; Model 3: $F(8, 35) = 1.86$, $p = .10$. Older: T1; Model 1: $F(3, 55) = 1.03$, $p = .39$; Model 2: $F(4, 54) = 1.36$, $p = .26$; Model 3: $F(8, 50) = 1.74$, $p = .10$. T2; Model 1: $F(3, 50) = 1.32$, $p = .28$; Model 2: $F(4, 49) = 1.32$, $p = .28$; Model 3: $F(8, 45) = 5.03$, $p < .001$.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

and PMT were all statistically significant predictors of TEAM A performance. Age was again statistically significant, but only for the youngest and oldest, possibly suggesting rapid development at that time, while urbanicity was statistically significant at Time 1 for both the younger and older children. Multicollinearity was not an issue on these regressions at Time 1 or Time 2 for either younger or older children as tolerance levels ranged from 1.00 to .57, above the 0.20 threshold (Hair et al, 2014).

The first three blocks of variables were then regressed on TEAM B, for the younger and older children at both Time 1 and Time 2 (see Table 26). Among the variables in block 1, age for the younger children at Time 2 was statistically significant, possibly indicating a developmental period, while gender, urbanicity, and age for other groups were not statistically significant. Block 2 resulted in a statistically significant ΔR^2 for the younger children at Time 1 and was a statistically significant predictor for this age group as well. Age for the younger children at Time 2 remained statistically significant. Adding the panel of face-to-face EF measures from block 3 resulted in a statistically significant ΔR^2 for the older children at Time 2 while all others ΔR^2 were not statistically significant. For the first time on a hierarchical regression (total sample: see Tables 7 and 8; split by age: see Tables 25 and 26), gender was a statistically significant predictor of a dependent variable, as it predicted TEAM B for the youngest and oldest children, possibly suggesting differences in developmental trajectory by gender occurring at this period. Of note, boys outperformed girls, an outcome unexpected based on extant literature. For the face-to-face EF measures, the TOH was statistically significant for the oldest children, while the HTKS was statistically significant for all but the youngest

Table 27

Hierarchical Regressions Comparing the Predictive Power of Individual Executive Function Measures for Numeracy Skill (TEAM A) for Younger and Older Children Across Two Time Points

	Younger						Older					
	T1			T2			T1			T2		
	β	Sig.	R^2	β	Sig.	R^2	β	Sig.	R^2	β	Sig.	R^2
DCCS	.51	.000	.533	.38	.009	.249	.15	.227	.157	.09	.467	.243
TOH	-.03	.831	.283	.20	.202	.144	.30	.022	.214	.29	.025	.310
Digit Span	.49	.000	.485	.23	.154	.153	.25	.048	.195	.31	.013	.325
PMT	.19	.115	.317	.36	.025	.213	.34	.007	.243	.29	.039	.300
HTKS	.36	.003	.404	.39	.013	.242	.28	.033	.204	.34	.009	.333

Note. The standardized regression coefficients (betas) and statistical significance levels reported are from hierarchal regressions containing the same control variables (age, gender, urbanicity). R-squares are model fit for the model containing that singular measure of executive function. TEAM = Tools for Early Assessment in Math; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders

Table 28

Hierarchical Regressions Comparing the Predictive Power of Individual Executive Function Measures for Geometry Skill (TEAM B) for Younger and Older Children Across Two Time Points

	Younger						Older					
	T1			T2			T1			T2		
	β	Sig.	R^2	β	Sig.	R^2	β	Sig.	R^2	β	Sig.	R^2
DCCS	.35	.009	.204	.28	.061	.188	.20	.133	.092	.15	.257	.097
TOH	.26	.056	.153	.05	.742	.115	-.03	.806	.054	.26	.065	.135
Digit Span	.22	.123	.133	.13	.430	.127	.13	.360	.068	.28	.046	.145
PMT	.27	.048	.157	.23	.172	.154	.24	.074	.107	.31	.045	.147
HTKS	.13	.347	.107	.43	.005	.276	.32	.018	.147	.56	.000	.347

Note. The standardized regression coefficients (betas) and statistical significance levels reported are from hierarchal regressions containing the same control variables (age, gender, urbanicity). R-squares are model fit for the model containing that singular measure of executive function. TEAM = Tools for Early Assessment in Math; DCCS = Dimensional Change Card Sort; TOH = Tower of Hanoi; PMT = Porteus Maze Test; HTKS = Head Toes Knees Shoulders children. As with all prior hierarchical regressions, multicollinearity was not an issue for the younger or older children at Time 1 or Time 2, as tolerance levels again ranged from 1.00 to .57, above the 0.20 threshold (Hair et al, 2014).

To determine how well each of the face-to-face EF measures predicted numeracy and geometry skill when used as a solitary measure across the four non-independent groups (Younger: Time 1 and 2; Older: Time 1 and 2), the first two blocks of this hierarchal regression were rerun with all EF measures replacing the DCCS (e.g., Block 2: demographic variables + HTKS, etc.). The beta and statistical significance levels are included for the EF measure within the model, as well as the variance explained by the model containing that measure. Once again, the DCCS was included in the table as a comparison, as it is measure frequently used as a solitary measure of EF and represents that analytical approach, (see Table 27 for numeracy skill, Table 28 for geometry skill). The DCCS explained 53% of the variance in numeracy skill at Time 1 for the youngest children and dropped to explaining 25% of the variability about 6 months later. While beta weights and statistical significance levels varied, only the HTKS was a statistically significant predictor of TEAM A at all four data points.

Compared to the predictive power of these measures for TEAM A (see Table 27), fewer EF variables predicted TEAM B (see Table 28). While the measure with the greatest beta at Time 1 for the youngest children was the DCCS, it was not a statistically significant predictor at the later time point. The measure that predicted a greater amount of the variance in geometry skill for older children at both points in time was the HTKS. No other EF measure showed this consistency either across time or age.

CHAPTER V

DISCUSSION

This chapter includes a discussion of the results for each of the three research questions. The limitations of the study are outlined, followed by a discussion of the unique contributions of this research, the connection of these results to Bronfenbrenner's PPCT model, as well as the impacts and future implications of the results. The final section is a general summary of this chapter.

Question 1

The first research question was about how the demographics, EF measures, and measures of numeracy and geometry performance related to one another. Question 1 was an important first step as it provided preliminary analyses into relationships between the various measures, as well as demographic variables of interest, specifically age, gender, and rural/urban categorization. To avoid redundancy, analyses with age, gender, and rural/urban categorization will be discussed later in the chapter.

Correlations between TEAM A and TEAM B (Time 1: $r = .49$; Time 2: $r = .63$) indicate that the two aspects of mathematical skill are highly related, but there are some independent elements. The larger correlation at Time 2 suggests that as numeracy and geometry skills improve across time they become more connected perhaps drawing upon similar cognitive abilities or perhaps indicating the maturation and consolidation of EF. The EF measures had statistically significant correlations with both TEAM A and TEAM B, but correlations were larger between TEAM A and the EF measures (see Table 5). Numeracy skill seems to be more strongly connected to EF than geometry skill for preschool-age children, something that, to our knowledge, has not previously been reported. It may be that geometry measures, like the TEAM B, assess skills in a way dependent mostly on inhibitory control (e.g., creating ABAB or ABBA patterns, identifying only specific shapes on chart, etc.). Because inhibitory control appears important, the implication is that “doing geometry” requires the inhibition of initial responses, giving the student time to think about nonintuitive responses to a problem. Working memory may play a part (e.g., remembering pattern, requested shape, etc.), likely because with an inhibition of response the student must remember what doesn’t work correct in order to discover what works.

Question 2

The second research question compared the predictive powers of three different assessment strategies (single measure, face-to-face panel, face-to-face panel and paper-and-pencil) on both numeracy and geometry performance. After analyses showed the BRIEF-P was not a statistically significant predictor of numeracy and geometry skill, the measure was removed from all subsequent analyses. Statistical nonsignificance was not expected as past researchers found connections between this measure and numeracy skill (Clark et al., 2010); however, Clark’s sample involved six-year-old children and for preschool-age children face-to-face EF measures may work better. Additionally, the composite score was used in analyses rather than the five subscales (Inhibit, Shift, Emotional Control, Working Memory, and Plan/Organize), turning the measure into a unitary measure of EF, which, as previously discussed, some researchers feel is appropriate for preschoolers (e.g., Espy et al., 2016).

Adding the DCCS at Time 1 (see Table 7), while controlling for demographic variables, made a statistically significant improvement in explaining the variance in numeracy performance. However, the DCCS made less of an improvement in explaining the Time 2 variance. For this sample, the strategy of using the DCCS as a solitary EF measure in predicting numeracy performance was more appropriate at Time 1. This finding raises the question of whether, for some children, a non-number-based EF assessment is a more accurate instrument to use with children who have had less practice with numbers. The inclusion of the panel of measures made a statistically significant improvement in explaining the variability in numeracy performance, but more so at Time 2. Other analyses, with the sample split into a younger and older sample, provides more insight into these findings and will be discussed later in this chapter.

Similar to numeracy skills, adding the DCCS to the model made a statistically significant improvement in explaining the variance in geometry skill (see Table 8). A difference between Time 1 and Time 2 was again found, as the DCCS appeared to be a better predictor of geometry skill at Time 1. Using a panel of face-to-face measures made a statistically significant improvement in explaining the variance in geometry skill, but only at Time 2. However, at Time 2 the only face-to-face EF measure with a statistically significant beta weight was the HTKS ($\beta = .38$, $p < .001$). The next analyses further explore this finding.

Next, the first two blocks from the hierarchical regressions were rerun to compare how each face-to-face EF measure compared to the DCCS (see Table 9). The measure explaining the most variance in numerical performance for the full sample was the digit span. The model with this working memory measure explained a slight percentage more of the variance in geometry skill than the DCCS, the attention set-shifting measure. Ranking the measures at Time 1 by percent of variance explained is as follows: digit span (R^2 = .43), DCCS (R^2 = .43), HTKS (R^2 = .42), PMT (R^2 = .41), and TOH (R^2 = .38).

Representative of the developmental changes that occur during the preschool years, the digit span at Time 2 had one of the lowest betas and the lowest R-square, while at Time 1 it explained the greatest percentage of variance. This may be a result of the timing of the assessments, or possibly maturation effects. That is, with maturation other skills became more predictive. At Time 2, the measure that explained the greatest variance in numeracy skill was the HTKS. Ranking the measures at Time 2 by R-squared is as follows: HTKS (R^2 = .43), TOH (R^2 = .40), PMT (R^2 = .39), DCCS (R^2 = .37), and digit span (R^2 = .36).

Comparing Time 1 and Time 2, measures increased (HTKS: $\Delta R^2 = +.011$; TOH: $\Delta R^2 = +.019$) or decreased in explanation of variance (PMT: $\Delta R^2 = -.018$; DCCS: $\Delta R^2 = -.060$; digit span: $\Delta R^2 = -.069$). Inconsistency between data points demonstrates how different studies may find dissimilar relationships between EF measures and the dependent variable in question (e.g., numeracy skill). Later analyses for question 3 provide insight into the influence that age had on the relationships between EF measures, numeracy, and geometry performance.

Compared to the relationship between EF and numeracy skills (see Table 9), the EF measures used in this study explained less of the variance in geometry skills (see Table 10). Given its focus on visual discrimination, perhaps it is not surprising that the measure explaining the greatest percentage of variance in geometry skill (R^2 = .21) was the DCCS. Ranking the measures at Time 1 by R-squared are as follows: DCCS (R^2 =

.21); PMT (R^2 = .19); HTKS (R^2 = .18); digit span (R^2 = .17); and TOH (R^2 = .15); however, beta weights for both the digit span and TOH were not statistically significant. The DCCS is a measure of set-shifting and both the PMT and HTKS are measures of inhibitory control, suggesting set-shifting ability and ability to inhibit may play a part in understanding geometry problems. To date, these relationships between EF and geometry skill have not been examined.

At Time 2, EF measures accounted for more of the variability in geometry skills than at Time 1 (see Table 10), yet explained less of the variance compared to numeracy skill (see Table 9). At Time 2 the measure explaining the most variance in geometry skill was the HTKS. The measures at Time 2 ranked by R-squared are as follows: HTKS (R^2 = .36); PMT (R^2 = .23); DCCS (R^2 = .22); digit span (R^2 = .21); and TOH (R^2 = .21), although the digit span and TOH models had statistically insignificant beta weights. The HTKS, a measure of complex inhibitory control, and the PMT, a measure of simple inhibitory control, appeared to account for more of the variability in geometry skill.

All measures explained more variance in Time 2, suggesting the relationship between EF aspects and geometry skill improved between Times 1 and 2. In other words, with continued development of cognition, the link between EF and geometry also increased. Of note, the model with HTKS explained more than double the percentage of variability in geometry skill at Time 2, suggesting a relationship between complex inhibitory control and geometry skill.

Question 3

The third research question focused on the predictive powers of three different assessment strategies (single measure, face-to-face panel, face-to-face panel and paper-and-pencil) by age, gender, or urbanicity relative to preschool-age children's numeracy and geometry skill. Initial analyses included correlations and a 3-way ANOVA (age * gender * sample). Next, the sample was split into a younger and older group, and hierarchical regressions for each sample were run for both numeracy and geometry skill with multiple blocks, including: block 1, demographic variables of age, sample, and gender; block 2, the DCCS; and block 3, the panel of face-to-face EF measures (DCCS, TOH, digit span, PMT, HTKS).

Correlations were repeated for both the younger and older children at Times 1 and 2 (for younger sample see Table 15; for older sample see Table 16). With the sample split into a younger and older age group, age was no longer highly correlated with all variables. With the sample split, and with two waves of data collection about six months apart, the changes that occur because of rapid development become apparent. Study results and extant literature (e.g., Bull et al., 2011; Wiebe et al., 2008) supported splitting the sample this way.

Gender only had statistically significant correlations with one variable, PMT, a measure of simple inhibitory control, at Time 2 for older children (see Table 16). Boys scored better than girls, a surprising finding as extant literature suggested that preschool-age girls have better inhibitory control (e.g., Bull et al., 2011; Matthews et al., 2009; Olson et al., 2005). The means and standard deviations (See Tables 18, 19, 20), as well as the ANOVA (Table 24) support this gender difference. Variation in assessment strategies may explain this difference. For example, Bull and colleagues and Olson and associates used Shape School (Espy, 1997) while Matthews and collaborators used HTKS (Ponitz, et al., 2009). The current study did not use Shape School and did not find gender differences on the HTKS. Comparing the sample's rural and urban participants found no statistically significant differences on income, indicating our rural sample was not financially disadvantaged compared to our urban sample, as some might assume.

Urbanicity correlated with numeracy skill (TEAM A) for both the younger and older children, but only at Time 1, supporting extant data suggesting school readiness disparities between rural and urban children at the start of the school year (e.g., Miller & Votruba-Drzal, 2013). These disparities may be a result of differences in contextual influence (Bronfenbrenner & Morris, 2006) between rural and urban children.

To explore the differences found by age, gender, and urbanicity relative to EF, numeracy, and geometry, a series of three-way ANOVAs were run. Statistically significant differences were found for the main effect of age for most variables at Time 1 (see Table 23), with an urbanicity * gender interaction for the DCCS (see Table 24). At Time 2, statistically significant differences for the main effect of age were found for all variables except Digit Span, with a sample * age interaction and a sample * gender interaction for HTKS (see Table 24). The findings were not surprising, given developmental change in typically developing children.

With extant (e.g., Bull et al., 2011; Wiebe et al., 2008) and empirical support for splitting the sample, hierarchical regressions were rerun for younger and older children, resulting in four non-independent groups (see Table 25 for TEAM A; see Table 26 for TEAM B). Adding the DCCS in block 2 resulted in statistically significant changes in model fit, but only for the younger children in this sample. This finding is important to note because when children were grouped together, Model 2 was statistically significant at Times 1 and 2, although less so for Time 2 (see Table 7). Regressions suggest the use of the DCCS as a singular measure of EF in predicting numeracy performance is only appropriate for younger children, below the sample mean age (52.58 months). However, the statistically significant two-way interaction effect between urbanicity and gender for DCCS performance suggests other factors such as gender and location also relate to TEAM A performance as well.

While age was a statistically significant main effect for HTKS at Time 1, at Time 2 there was a statistically significant 2-way interaction between Urbanicity * Gender and Urbanicity * Age for HTKS. Interactions suggest that urban boys, rural girls, and younger urban children did statistically significantly better than their counterparts, possibly because of unique demand characteristics that helped them perform (Bronfenbrenner & Morris, 2006). Perhaps urban diversity works more favorably for the development of HTKS skills for boys while rural diversity does the same for girls.

Adding the panel of face-to-face EF measures made statistically significant improvements on model fit for only the older children. This finding was not seen when the children were grouped together (see Table 6). Data suggest that, to capture the most variability in numeracy performance in a sample older than the mean age of this sample (52.58 months), a panel of face-to-face EF measures might be more appropriate.

While connections between EF and numeracy skill are better established, less is known about possible connections between geometry skill and EF. The relationship between EF and geometry skill is a dramatic difference from the relationship between EF and numeracy skill (see Table 27), where three of four models were statistically significant. Hierarchal regressions run with the total sample resulted in statistically significant models, but only because of age (see Table 7). When split into younger and older groups, age maintained a statistically significant beta weight but only for the younger children at Time 2, and the statistical significance was maintained when block 2 was added.

For the younger children at Time 1, the DCCS was a statistically significant predictor of geometry skill. In prior regressions with the whole sample (see Table 7), the model with the DCCS was statistically significant, yet when split by age, it was only significant for the youngest assessed (age: 47.26 months). This variation in results provides further evidence that the sample should be split into smaller age ranges when analyzing the EF skills of groups of children with a large range in ages. Additional hierarchical regressions were run to examine how other face-to-face EF measures would do as a singular measure in a study in predicting geometry skill, compared to the DCCS (see Table 28). Among the measures in this study, the measure that explained the greatest amount of variance in geometry skill across the four age groups was the HTKS, which was statistically significant for all but the youngest children. Based on these results, when selecting a singular measure, the HTKS appears to be the best EF measure in this study for predicting geometry skill followed by the DCCS.

When block 3 was added, the panel of measures made statistically significant improvements on model fit for only the older children at Time 2. This finding was not unexpected as older children have more developed aspects of EF (e.g., Clark et al., 2016), which could aid in geometry skill. Alternatively, the measures administered may be more reliable for older preschool children. Study data suggest that, to capture the most variability in geometry skill in a sample of children around 63 months old, a panel of face-to-face EF measures might be more appropriate.

The aforementioned results, while similar to those reported for numeracy skill, do provide insight into differences between numeracy and geometry skill. While the panel of EF measures used in this study appeared to be most appropriate for assessing numeracy skill for a sample of children around 58-months-old (see Table 25), to assess geometry skill, the panel of measures was most appropriate for a sample about six months older (age: 63.07 months; see Table 26). This may be because the relationship between geometry skills and EF develops later than the one between numeracy ability and EF, or it may be an artifact of the EF measures in the current study. However, it is interesting to note than if selecting a singular measure of EF, the HTKS appears to be the best choice for assessing both numeracy and geometry. Yet there appears to be about a six-month period where it is a better assessment of numeracy skill (see Table 27) than geometry skill (see Table 28).

Beyond comparisons of analytic strategy, these results also demonstrate how easily it is for scholars' findings to differ. As has been stated in extent literature (Carlson, 2005), assessments occurring within a year can show dramatic EF improvement. Although EF is strongly connected to numeracy skill, it is clear that regression weights can increase or decrease across relatively short spans of time. An example from the current study would be the digit span, which was highly predictive at Time 1 of numeracy performance as a solitary measure of EF but about six months later was not statistically significant. The explanation for this change is unknown, but as children did better on the TEAM A at time 2, they likely utilized other EF abilities to accomplish more complex mathematic problems. This suggests that the seemly contradictory findings in extent research, as cited previously, might be an artifact of the age of the child at that time point.

Finally, it is interesting to note that multicollinearity between the five face-to-face EF measures was not an issue for any of the regressions or correlations. While each measure was selected to measure EF in differing ways, stronger relationships between measures would be expected if they were all measuring a single construct, rather than unique but interrelated aspects. While this does not solve the unitary vs. componential debate, it does suggest value in utilizing multiple EF measures.

Limitations

Although this study makes a unique contribution, there are limitations to address. Difficulties in gathering longitudinal data, especially from a rural area as distant as the one assessed, resulted in missing data. This resulted in a drop between Times 1 and 2 of nine participants, 14.1% of rural sample. In comparison, only one urban participant, 1.9%, was lost. However, *t* tests found no statistically significant differences on any of the variables used in analyses between those who remained in the study and those who did not. Additional missing data were from parent and provider demographics, and so those variables were limited in their use.

Another limitation was sample size preventing more in-depth analyses between groups. For example, because some teachers were connected to only a few children, nested analyses could not be used to address any research questions. Although in this study the urban area selected to recruit from had more centers than the rural area, there was difficulty recruiting an urban sample, which is surprising. This is partially explained by center director fatigue in participating in research, with some opting out of participating after only an initial interaction. However, while rural providers and parents were more likely to participate, it was more difficult getting rural parents to return assessment materials.

Contributions, Implications, and Future Research

Although many scholars have examined the relationships between EF and numeracy skill, this is the first study of its kind to compare the various EF assessment strategies in predicting both numeracy and geometry skill and to compare these strategies across two age points and rural and urban populations. This resulted in significant findings regarding when a solitary measure should be used rather than a panel of face-to-face measures, and which measure might be most predictive of both numeracy and geometry skill. Additionally, the relationship between EF and geometry was examined, and seems to be connected to complex inhibitory control, something previously undiscovered.

While some scholars have elected to use only a solitary measure of EF in their studies of preschool-age mathematics (e.g., McClelland et al., 2007), the results of this study show that the DCCS, a measure frequently used in such conditions (e.g., Buss & Spencer, 2014), seems more appropriate for children below the sample mean age of 52.58 months. Results suggest that above this age, the DCCS is no longer a statistically significant predictor of numeracy skill. However, for scholars seeking a singular measure to use in a study, whether limited by funds, time, or some other research constraint, the HTKS was a statistically significant predictor of numeracy skill across this sample. As the HTKS has been used as a solitary EF measure in research (e.g., Ivrendi, 2011), the results of this research support its use in this capacity.

While other scholars elect to use a panel of face-to-face measures, as demonstrated by Carlson (2005) reporting the use of 11 in one study, this study provides insight into this strategy as well. Analyses found that prior to the mean age of the sample (52.58 months), adding a panel of measures does not make a statistically significant improvement on *R*-squared, with better regression weights for older samples. Therefore, this study posits that because EF is less developed in preschool-age children, a singular EF measure, if found to be appropriate for the age, might be more efficient than a panel of measures. Prior research has found that older children have more developed EF aspects (e.g., Clark et al., 2016), and the current research suggests that as these aspects develop they begin to influence numeracy abilities, making a panel of measures an appropriate analytic strategy for more cognitively developed children.

Findings suggest that EF relates to numeracy and geometry differently, something previously unexplored. While all individual measures predicted numeracy skill at two points in time for the two samples (younger and older), the measures had fewer connections to geometry skill. This demonstrates that while numeracy and geometry are related, they have components that involve differing aspects of EF. The HTKS was predictive of geometry skill for three of the four data points. That models with this single EF measure were most predictive of both numeracy and geometry suggests future analyses are needed to clarify these relationships.

This study found that utilizing a panel of EF measures to predict geometry skill may be inefficient unless the sample is older, mirroring the numeracy results, but also offsetting the results by about 6 months. This relationship between the effectiveness of the panel, as well as the relationship between these mathematical constructs and the

HTKS, suggests that geometry and numeracy skill may have similar developmental trajectories, but that geometry develops after numeracy, a possible delay of about six months. Future studies will need to replicate these findings as this may be an artifact of the current study.

The current study supports numeracy performance disparities between rural and urban children (e.g., Miller & Votruba-Drzal, 2013), unrelated to differences in income. Besides differences on numeracy performance, the only other measure with a statistically significant difference between samples was on the working memory measure (forward digit span), supporting extant literature (Tine, 2014). Additionally, these results added to the literature by finding that there were no statistically significant differences between the rural and urban children on geometry skill. However, additional studies will need to determine if differences between rural and urban children occur if samples are more economically diverse.

Bronfenbrenner's PPCT model (Bronfenbrenner & Morris, 2006) can provide a lens to help review the influence of these demographic variables. The results show that a demand characteristic, such as the age of the child, plays a very significant role. For example, statistically significant differences were found on the dependent and independent variables by age, suggesting that the prime assessment strategy should be determined by the age of the child. Additionally, it was found that analyses splitting samples of children into smaller age groups was found to allow for more refined results particularly to the EF measure used.

Another demand characteristic, and component of the person aspect of the PPCT model, is gender, which had little influence on the variables used in these analyses. The only dependent or independent variable related to the gender of the child was the PMT. The results were surprising as they suggest boys outperformed girls on this simple inhibitory control measure, while extent literature suggested the opposite would be found (e.g., Bull et al., 2011). However, this may be connected to a different facet of the PMT, such as the potential role of spatial reasoning, and boys may have more spatial reasoning experiences than girls (e.g., Clements & Battista, 1992).

An additional component of the PPCT model was the role of contextual influences, specifically the influence of the child being raised in a rural or urban environment. Results suggest that children raised in a rural environment, regardless of age, family income, or maternal education, scored lower than urban children on the numeracy skills measure. Perhaps these contextual differences found in rural vs. urban areas create different cultural nuances, and perhaps one is more conducive to numeracy skills growth than the other.

Future studies will also need to reexamine these relationships with alternative EF measures. For example, results demonstrate that the HTKS is a statistically significant predictor of both numeracy and geometry skill across most of (geometry), or all (numeracy), of this sample. This suggests that the EF aspect responsible for geometry skill during the preschool years is inhibitory control, or more specifically complex inhibitory control. This type of measure includes some working memory input in addition to inhibitory control, and is what the HTKS is designed to measure; however, until this is replicated with an alternative complex inhibitory control measure, it is difficult to know what facet of the HTKS might be significant.

Summary

There have been many studies examining the relationships between EF and mathematics. However, these have been limited to assessments of numeracy skill, and the literature is sparse to date on the relationships between EF and geometry skill. This study found that while EF and geometry are connected, there are fewer connections than those found between EF and numeracy skill. Assessment strategies were compared, with the result that the age of the child needs to be considered in all selection of measures. Some measures may be used as a solitary EF measure in a study; to assess both numeracy and geometry skill results suggest the HTKS be used. A panel of face-to-face measures can have statistically significant improvements on model fit, but only for children with more developed EF. While differences were found between rural and urban children on numeracy performance, no statistically significant differences were found between groups on geometry skill. Gender differences were found, but only at Time 2 for older children, and only on a single EF measure designed to assess simple inhibitory control. The difference, supported by varying analyses, suggests that boys outperformed girls in the study's sample, while extant data suggested the inverse relationship would be discovered.

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APPENDICES

Appendix A

Recruitment Letter

Dear Provider,

We are writing to inform you of an exciting study coming your way: The SUNBEAM Project. Researchers from Utah State University will be looking at rural and urban preschool children to study their environments and school readiness.

What do we need from you? We will be asking participating providers and teachers to complete some surveys and help us contact parents so that we can explain our study and ask for their participation. If they agree, we will then come to your location to interview the children and play some games with them. Surveys and interviews would occur at two time periods about 6-8 months apart (roughly the beginning and end of the school year).

What do you get in return? You will receive books about math or math games and supplies for your child care program.

We will contact you soon to see if you would like to learn more about our project and to answer any questions you may have. You are also welcome to contact us at SUNBEAM.USU@gmail.com at any time.

Thank you!

The SUNBEAM Project Team

Ann Austin, Ph.D. Brionne Thompson, M.Ed. Jacob Esplin, B.S.

Appendix B

Dimensional Change Card Sort (DCCS)

Demonstration

"Here's a blue star and a red circle. Now, we're going to play a card game. This is the color game. In the color game all the blue ones go here *[pointing to the tray with blue star]***, and all the red ones go there** *[pointing to the try with the red circle]***."** Sort one type of test card (e.g., a blue circle) by color, saying, **"See here's a blue one. So it goes here"** *[place it face down in the tray with blue card]*. Repeat the pre-switch rules, **"If it's blue it goes here, but if it's red it goes there."** Show children the other type of test card (e.g., red star), and say, **"Now here's a red one. Where does this one go?"**

Correct:

> **"Very good. You know how to play the color game."** If they point, say, **"Can you help me put this red one down?"** Ensure that the card is placed *face down* in the appropriate tray, turning the card over if necessary.

Incorrect:

> **"No, this one's red, so it has to go over here in the color game. Can you help me put this red one down?"** Ensure that the card is placed *face down* in the appropriate tray.

Pre-Switch Phase

"Now it's your turn. So remember, if it's blue it goes here, but if it's red it goes there." Randomly select a test card (e.g., a red star), show it to the child, and label it by the relevant dimension only. Say, **"Here's a red one. Where does it go?"** The child may take the card and place it in a tray or simply point to one of the trays, in which case you may sort the card for them. In either case, ensure that the card is placed face down in the appropriate tray.

Correct/Incorrect:

> **"Let's do another one" or "Let's do it again," or "How about another one?"** and proceed to the next pre-switch trial; that is, respond to children in a neutral, non-evaluative, noncorrective fashion (e.g., <u>**do not say "Okay"**</u>).

On each pre-switch trial, <u>repeat the pre-switch rules</u>, select a test card (ensuring that the same type of test card, e.g., a red star, is not selected on more than two consecutive trials), show the card to the child, label it by the relevant dimension only, and ask the child where it goes: **"Here's a red one, where does it go?" or "Here's a red one, where does this one go?"**

Stop after six pre-switch trials and proceed without pausing.

Switch Phase

"Now we're going to play a new game. We're not going to play the color game anymore. We're going to play the shape game. In the shape game, all the circles go here *[pointing to the tray with the circle]***, and all the stars go there** *[pointing to the tray with the star]*. **Remember, if it's a star, put it here, but if it's a circle put it there. Okay?"**

Do not remove any previous cards or pause between pre- and post- switch phases. Select a test card (still ensuring that the same type of test card is not selected on more than two consecutive trials), show the card to the child, label it by the relevant dimension only, and ask, **"Where does this one go?"**

Correct/Incorrect

"Let's do another one" or "Let's do it again," or "How about another one?"

If five out of six post-switch trials are correct, proceed to boarder

Border Phase

Pull out second pack of cards (3 circles, 4 stars, 3 border circles, 4 border stars)

"Okay, you played really well. Now I have a more difficult game for you to play. In this game, you sometimes get cards that have a black border around it like this one *[showing a red star with a border]***. If you see cards with a black border, you have to play the color game. In the color game, red ones go here and blue ones go there** *[pointing to the appropriate trays]*. **This card's red, so I'm going to put it right there** *[placing it face down in the appropriate tray]*. **But if the cards have no black border, like this one** *[show a red star without a border]***, you have to play the shape game. In the shape game, if it's a star, we put it here, but if it's a circle, we put it there** *[pointing to the appropriate trays]***. This one's a star, so I'm going to put it right here** *[placing it face down in the appropriate tray]*. **Okay? Now it's your turn."**

On each trial, repeat the rules **"If there's a border, play the color game. If there's no border, play the shape game,"** select a test card (ensuring that the same type of test card – with or without a border – is not selected on more than 2 consecutive trials), label the card as having a border or not, and ask the child where it goes. After the child sorts it, simply say, **"Let's do another."** For example, ***"Remember, if there's a black border, you have to play the color game. But if there's no black border, you have to play the shape game. Here's one with a black border. Where does it go? [child sort] Let's do another."*** Respond to the children in a neutral, non-evaluative, noncorrective fashion.

Troubleshooting

Problem	**Solution**
Children hesitate	Label the card by the relevant dimension and ask where it goes (e.g., **"Here's a star, where does it go?"**). If the child still hesitates, say, **"Let's do another one,"** return the skipped card to the pile of to-be-sorted cards, select a new card, label it by the relevant dimension, and ask where it goes.
Children refuse to complete the task	If a child refuses to continue sorting, suggest that he or she may point to the correct box and show you where each card goes. If the child refuses to do this, then terminate the task, as their data will be unusable unless all trials are completed.
Children change response	Allow children to change their responses, scoring only their final response. Do not provide evaluative feedback. Simply say, **"Are you sure?"** and then proceed to the next trial, saying, **"Let's do another one."**
Children ask for feedback	Do not provide evaluative or corrective feedback. Simply encourage them to keep playing, saying, **"Sort the card,"** or **"let's do another one,"** as appropriate.
Children pick up previously sorted cards	Prevent children from picking up previously sorted cards. Tell them, **"Those cards have to stay there, but let's do another one."**
Children take a break during the task	Discourage children from taking a break until the procedure has been completed, saying, **"We're almost done."** If children need to take a break during demonstration, pre-switch, or border phases, repeat the interrupted step when they return and then complete the procedure. Only use data from the completed (re-administered) step, not the interrupted one. Children should not take a break during the post-switch phase; this would render the data unusable.

Dimensional Change Card Sort (DCCS) Scoring

From (Zelazo, 2006)

“Assign a score of 0 if children fail the pre-switch phase of the standard version; assign a score of 1 if they pass the pre-switch phase of the standard version but fail the post-switch phase; assign a score of 2 if they pass both the pre- and post-switch phases of the standard version but fail the border version; assign a 3 if they pass both phases of the standard version and pass the border version.”

Fail the pre-switch phase	Less than 5 correct	0
Pass the pre-switch phase but fails the post-switch	Less than 5 correct	1
Pass both the pre- and post-switch but fails border	Less than 9 correct	2
Pass both standard and border version		3

Dimensional Change Card Sort (DCCS) Date ______________________

Name ______________________ Examiner ______________________

Location ______________________ Score ______________________

Pre-switch (Color Game)

Accurate	Inaccurate

[Correct __/6]

Post-switch (Shape Game)

Accurate	Inaccurate

[Correct __/6 – **5 needed to proceed**]

Border Version (Border – Color; No Border – Shape)

Accurate	Inaccurate

[Correct __/12]

Appendix C

Tower of Hanoi (TOH)

Tower of Hanoi

Cover Story (adapted from Klahr & Robinson, 1981)

Once upon a time there was a blue river (experimenter points to space between rows of pegs). On your side of the river there were three brown trees. On my side there were also three brown trees. On your side there lived three monkeys: a big red daddy (present red disk and place on peg), a medium size purple mommy (present and place), and a little blue baby (present and place). The monkeys like to jump from tree to tree but there are things they always do. They like to only move one monkey at a time, a bigger monkey can’t get on a smaller monkey because the smaller monkeys aren’t strong enough to carry the bigger monkeys, and the monkeys like to hide in the trees and don’t like to touch the ground; they live on your side of the river. (Establish legal and illegal jumps). On my side there are also three monkeys: a daddy, a mommy and a baby (introduce Experimenter’s discs). Yours are copycat monkeys. They want to be just like mine, right across the river from mine. Mine are all stacked up like so (points to goal state on examiners side of the table) yours are like so (points to child’s side of the table). Yours are very unhappy because they want to look like mine, but right now they are a little mixed up. Can you tell me what to do in order to get yours to look like mine? How can I get your daddy across from my daddy (etc.)?

3 Rules of the task

1) Only one monkey can move at a time
2) A bigger monkey cannot sit on a smaller monkey
3) The monkeys have to stay on the pegs if they are not in the child’s hand

Go onto the next trial upon solution or when a child has made 20 moves. Discontinue after 2 consecutive failures

Failure is:

1) Fail to make a legal move
2) Refuse to make any moves

Tower of Hanoi Trials

	C-I Moves	Start	Goal	Move 1	Move 2	Move 3	Move 4	Move 5	Move 6	Move 7
P1	0	23/-/1	123/-/-	1AC						
P2	0	3/2/1	123/-/-	2BA	1CA					
1	0	3/1/2	123/-/-	2AC	1BC					
2	1	3/12/-	123/-/-	1BC	2BA	1CA				
3	1	-/12/3	123/-/-	3CA	1BC	2BA	1CA			
4	2	1/3/2	123/-/-	1AC	3BA	1CB	2CA	1BC		
5	2	1/23/-	123/-/-	2BC	1AC	3BA	1CB	2CA	1BA	
6	2	-/-/123	123/-/-	1CA	2CB	1AB	3CA	1BC	2BA	1CA

Tower of Hanoi Date ________________________

Name ________________________ Examiner ________________________

Location ________________________ Score ________________________

#	Min	Moves	Completed	Fail	
1	2				
2	3				
3	4				
4	5				
5	6				
6	7				

3 Rules of the task

1) Only one disk can move at a time
2) A bigger disk cannot sit on a smaller disk
3) The disks have to stay on the pegs if they are not in the child’s hand

Go onto the next trial upon solution or when a child has made 20 moves.

Discontinue after 2 consecutive failures

Failure is:

1) Fail to make a legal move

2) Refuse to make any moves

Appendix D

Digit Span

Digit Span Date ________________________

Name ________________________ Examiner ______________________

Location ________________________ Score ________________________

"We're going to play a copy-cat game. I'm going to say some numbers, and I want you to copy me and tell me the same numbers. We're going to see how many numbers you can remember. If I say, 1-2-3, what do you tell me? (Wait for response, prompting if necessary). What if I say 7-4-5, what do you tell me? (Wait for response, prompting if necessary). Now I'm going to start with two numbers, and we are going to see how many you can remember."

A	6 7	F	1 2 8 9 4 9 8
B	7 1 5	G	7 7 2 3 6 9 5 4
C	8 7 6 3	H	2 1 7 9 1 6 8 5 1
D	5 2 5 9 4	I	6 3 6 9 2 4 9 5 2 5
E	5 3 6 7 6 9	J	9 8 3 8 9 4 9 8 2 1

Instructions: Repeat the first two digits at a rate of one digit every two seconds. If repeated correctly circle the last digit in the span, go to the next span, adding a digit to the length. If recalled incorrectly, cross out the last number in the span (identifying its length). Go to the next list and provide a sequence of equal length to the one missed. Continue until the child fails on two attempts of any given span length. If refusal, place an X on the score line.

Appendix E

Porteus Maze Test (PMT)

Porteus Maze Instructions

Year III

The examiner should place the maze test sheet for Year III in front of the youth and say, ***"Can you see there are two black lines here on this paper? I want you to use the pencil and draw between the black lines as carefully as you can without touching the lines or lifting your pencil."*** The examiner should illustrate touching the lines of the maze by drawing a line approximately one inch long along the path, starting from the S and in the direction of the arrow. The examiner should then say, ***"Be sure to keep the pencil right between the lines."*** If necessary, the examiner can hold the youth's hand and guide the pencil to the first turn in the maze path.

Year IV

After presenting the test, the examiner should say, ***"Do this one just the same way. Start here (point to the S), and go through the maze, staying between the lines. Be sure and do not cross any lines."*** As in the test for Year III, the examiner may indicate the way in which the pencil line is to begin by drawing a short one-inch line to demonstrate, <u>then erasing it</u>.

Year V

The following instructions should be read verbatim: ***"These are all roads, and the lines are fences. Some of the roads are open, and some are closed."*** Point to the opening at the end of the fourth road and then say, ***"This road is open, and if you are driving in a car you could get out here."*** Indicate, without touching the paper, the motion of passing through the open space.

Then point to the opening at the end of the sixth road. Again, indicate the motion of passing through the open space. Then point to the seventh road and show the line across the end, blocking its exit. Simultaneously say, ***"But there is a fence here, so you could not get out this way."***

The examiner should then point to the lines blocking the exits at the fifth, third, second and first roads, in that order. Indicate at each point that an exit cannot be reached through these points. While demonstrating these blocked exits, the examiner should say, ***"And there is fence here, here, here and here, so you cannot get out this way."*** Then the examiner should say, ***"Now take the pencil and start here (indicating the S), go down the road and go out on the first open road you come to."***

"One more thing you must remember – you can stop anywhere and look as long as you like, but try not to lift your pencil off the paper until you have drawn right to the end of the maze."

If the youth succeeds on the first trial, continue with the test for Year VI. If the child fails by going into a blocked road, or going out the sixth road, the instructions are repeated verbatim for Year V, and a second trial on a new maze form is administered. If they succeed on the second trial, continue to Year VI.

Year VI

The examiner presents the maze test and says, ***"Start here (indicating S) and find your way out here (point out the arrow at the other end). You may go along any road you like, but you must not go into any blocked roads or cross any of the lines."*** The examiner should then repeat, ***"Start here (indicating S) and find your way out here (pointing out the arrow at the other end). You may stop and look as long as you like, but you must keep your pencil on the paper."*** Allow only two trials of the test. If the child immediately cuts across a line, the rule regarding the error of crossing lines is reiterated. The instructions should be repeated verbatim during the second trial.

Year VII

The examiner presents the maze test and says, ***"Start here (indicating S) and find your way out in the same way as before, without going into any blocked places, and without crossing any lines."*** Allow only two trials.

Years VIII-X

The examiner should present the maze tests one by one. For each year test, the examiner should say, ***"Start here and find your way out to the open place."*** The examiner should indicate the S to the child to show where to start, <u>but should not indicate where the exit is</u>.

In any of these tests, the child may hesitate, point to what they believe the exit is and ask, "Is this the open place?" The examiner should replay to this question by saying, "You must find the open place for yourself." Allow only two trials for each year test.

Porteus Maze

Rules:

Examiner should sit facing the youth with their fingertips on the test sheet squarely in front of the child being careful not to present the maze upside down.

Pencil should not be lifted off paper once started. If they do, they need to be told not to do this, but no penalty. Occurs frequently – warned repeatedly, but no penalty.

No tracing maze with finger in air or on paper.

Never let any error go un-penalized, no matter how slight or how quickly corrected, unless it's an obvious slip from poor motor control.

Replace sheet after mistake, even if the mistake was at the beginning.

At any point where a subject draws through an imaginary line across the entrance to a blind street or alley, the design is removed and an "unsuccessful trial," *not a failure*, is recorded.

Never allow more trials on a maze than instructions provide. This provides practice for the youth.

It is inadvisable to use the same maze test sheet for more than one trial. If a mistake is made near the very beginning of the maze, it is permitted to replace the maze test sheet with a new one for the same age year and then restart without penalty.

For tests VIII or higher, the opening at the end is not pointed out and if asked the child should be told they need to find their own way out.

End when two sequential/consecutive tests are failed, failed being when the child is unable to complete the maze in the number of trails provided. If a test is failed, and the following test is successful, that same test is presented inverted. In its inverted form, the same number of trials is allowed for that maze (e.g., child fails on Test IV, succeeds on the first (or second) trial of V, and is then presented with an inverted Test V, and is given two trials to successfully complete).

Errors:

1st error of beginners:

At any point where a subject draws through an imaginary line across the entrance to a blind street or alley, the design is removed and an "unsuccessful trial," *not a failure*, is recorded. Cutting across from one alley to the next to avoid drawing around to reach an opening is scored as a test age error and is at once recorded as an unsuccessful trial. No right to make any assumption of accidental error.

2nd error of beginners:

The examiner neglecting to invert and repeat a test design if, after the subject has failed in the allotted number of trials in the test for the previous year, he succeeds in passing the next higher test. The success, if accidental, is not accepted. The test is reversed and the worse performance of the two presentations, ordinary or inverted, is recorded for scoring purposes. If two trials are required, a half year is deducted from the score. Failure is recorded if there are two unsuccessful trials below X.

3rd error of beginners:

The examiner pointing out the opening at the end of the VIII year or a higher test. Frequently the individual will ask, “Where do I get out?” Except in the case of the V, VI and VII Year designs, the subject should be quietly told that s/he will have to find his/her own way out.

Do not allow the youth to correct their own errors by retracing from their original course through the maze. The administration should be stopped as soon as possible when an error is made, and the individual should be given a new maze sheet of the same year. If this occurs, the examiner should say, “You cannot get out of the maze that way.” After being given a new sheet, the subject should be instructed to begin again.

Drawing a line that will immediately lead into a block area or dead end (examiner needs an imaginary “gone to far” line that when crossed ends test).

Going through numerous solid lines in an obvious manner to avoid the obstacles of the maze is an error. Inadvertent crossing is not penalized. Not a fine motor test. Touching sides is not an error. No need to say to be careful.

Cutting across from one alley to the next to avoid drawing around to reach an opening is scored as a test age error and is at once recorded as an unsuccessful trial.

If they say, “There’s no way out” and lift their pencil, this is scored as an unsuccessful trial, even though they might be on the right course. If they make this remark, but don’t lift their pencil, wait a couple of seconds and then remove the maze, scoring it as an unsuccessful trial.

Cannot correct any errors – as soon as possible after an error provide a new sheet

Language Barrier:

For children where a language barrier exists between themselves and the examiner, the maze test for Year III can be used for demonstration purposes. In this scenario, the examiner would take a new maze test sheet and complete it. The examiner then gives the child a new test maze test sheet, and proceeds with the original instructions for this level task.

Physical Handicap:

Using a pointer, rather than a pencil, is admissible if special circumstances are present, such as a physical disability or handicap (generally not recommended because it's hard to see small errors and there is no tangible record to reference).

Porteus Maze Scoring

General Guidelines

At any point where a subject draws through an imaginary line across the entrance to a blind street or alley, the design is removed and an "unsuccessful trial," *not a failure*, is recorded.

Cutting across from one alley to the next to avoid drawing around to reach an opening is scored as a test age error and is at once recorded as an unsuccessful trial.

End when two sequential/consecutive tests are failed, failed being when the child is unable to complete the maze in the number of trails provided. If a test is failed, and the following test is successful, that same test is presented inverted. In its inverted form, the same number of trials is allowed for that maze (e.g., child fails on Test IV, succeeds on the first (or second) trial of V, and is then presented with an inverted Test V, and is given two trials to successfully complete).

Ceiling:

The highest-level test passed in the allowed number of trials; then deduct ½ year for every unsuccessful trial. If both trials on a given year are unsuccessful, it is a failure and there is a 1-year deduction if it is beneath the ceiling level.

Year III:

On either trial if there are no more than three errors of any kind made. Any attempt at following the outline of the test is indicative of ability at about a two-year level.

Year IV:

On either trial if there are no more than two errors made in total.

Year V:

6 Possibilities

1- The child goes out the first open road (fourth road) on the first trial. **Full credit**
2- The child goes out the second road (sixth road) on the first trial, and on the second trial, goes out the correct opening. **Full credit**
3- The child goes out the second open road on both trials. **Half credit** is given for this.
4- The child goes into a blocked road the first trial and goes out the correct opening the second trial. **Half credit** is given

5- The child goes into a blocked road on the first trial and goes out the second opening on the second trial. **No credit** is given, however the testing proceeds until there have been two successive failures.

6- The child goes into a blocked road on both trials. This is considered a failure, **no credit** is given, and the rule stating that no more than two trials are allowed for any given test is enforced.

Porteus Maze

Date ____________________

Name ____________________

Examiner ____________________

Location ____________________

Score ____________________

Year III

T1 E	
T2 E	
Fail	

Deductions ____________________

Year IV

T1 E		IT1 E	
T2 E		IT2 E	
Fail		Fail	

Deductions ____________________

Year V

T1 E		IT1 E	
T2 E		IT2 E	
Fail		Fail	

Deductions ____________________

Year VI

T1 E		IT1 E	
T2 E		IT2 E	
Fail		Fail	

Deductions ____________________

Year VII

T1 E		IT1 E	
T2 E		IT2 E	
Fail		Fail	

Deductions ____________________

Year VIII

T1 E		IT1 E	
T2 E		IT2 E	
Fail		Fail	

Deductions ____________________

Year IV

T1 E		IT1 E	
T2 E		IT2 E	
Fail		Fail	

Deductions ____________________

Year X

T1 E		IT1 E	
T2 E		IT2 E	
Fail		Fail	

Deductions ____________________

Appendix F

Head Toes Knees Shoulders (HTKS)

Head Toes Knees Shoulders Task Script

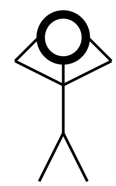
Administer the task while seated: the child should stand, about 3 feet from you, throughout the entire task. The person symbol indicates to demonstrate the correct body motions.

If the child produces the correct response immediately, score the item "2". If they self-correct right away, without prompting, score the item "1". If they do not touch the correct part of their body at all, score the item "0".

Copy Practice

Now we're going to play a game. The game has two parts. First, I want you to copy what I do.

Touch your head.
(Wait for the child to put BOTH his/her hands on head.)



Good! Now touch your toes.
(Wait for the child to put his/her hands on toes.)
Good!

(Repeat the two commands <u>with motions again</u>, or until the child imitates you correctly. Keep having the child copy your motions.)

Touch your head.

Touch your toes.

Part I Training

Now we're going to be a little silly and do the opposite of what I say. When I say to touch your head, **instead** ***of touching your head, you touch your toes. When I say to touch your toes, you touch your head. So you're doing something different from what I say.***

(**Ask A1** and circle the child's response on the code sheet)

If s/he <u>hesitates or responds incorrectly</u>, say EXPLANATION, "***Remember, when I say to touch your head, you touch your toes, so you are doing something different from what I say. Let's try again.***" (Repeat A1 again)

If s/he <u>responds correctly</u>, say, "***That's exactly right***" and proceed to A2:

(**Ask A2** and circle the child's response on the code sheet)

If s/he hesitates or responds incorrectly, say EXPLANATION, "***Remember, when I say to touch your toes, you touch your head, so you are doing something different from what I say. Let's try again.***" (Repeat A2 again)

If s/he responds correctly, say, "***That's exactly right***" and proceed to B2:

You may re-explain (use EXPLANATION below) up to three times in the TRAINING (A1-A2) and PRACTICE (B1-B4) sections. If you have already given two explanations during the TRAINING questions, then you may correct them only once more in the PRACTICE items. If the child cannot do the task after the third explanation, administer the 10 test items anyway.

EXPLANATION: ***Remember, when I say to touch your toes (head), you touch your head (toes), so you are doing something different from what I say. Let's try again.***

Part I Practice: (See Score Sheet)

We're going to keep playing this game, and you keep doing the opposite of what I say.

If the child does not understand the task, you will have gone through the directions at most four times (once at the beginning, and up to three times in the TRAINING and PRACTICE sections). **DO NOT explain again after testing begins.**

(Administer Part I)

Part II Training

Administer Part II if child responds correctly to 5 or more items on Part I of the task, or if child is in kindergarten or beyond.

Ok, now that you've got that part, we're going to add a part. Now, you're going to touch your shoulders and your knees. First, touch your shoulders.

(Touch your shoulders; wait for the child to touch his/her shoulders with both hands)

Now, touch your knees.

(Touch your knees; wait for the child to touch his/her knees with both hands)

Repeat with four alternating commands (no demo) until the child has imitated you correctly or it is clear the child does not comprehend the task.

> ***Touch your shoulders***
>
> ***Touch your knees***
>
> ***Touch your shoulders***
>
> ***Touch your knees***

Ok, now we're going to be silly again. You're going to keep doing the opposite of what I say like before. But this time, you're going to touch your knees and shoulders. EXPLANATION ***When I say to touch your knees, you touch your shoulders, and when I say to touch your shoulders, you touch your knees.***

(**Ask C1** and circle child's response on the code sheet)

<u>If response is correct,</u> say *"**Good job! Let's practice**"* and proceed to D1.

<u>If the response is incorrect,</u> say EXPLANATION "***Remember, when I say to touch your knees,*** **instead** ***of touching your knees, you touch your shoulders. I want you to do the opposite of what I say. Let's try again."*** Proceed to D1

EXPLANATION (up to 3 times total on both rules and practice): ***Remember, when I say to touch your knees (shoulders), you touch your shoulders (knees), so you are doing something different from what I say. Let's try again.***

Part II Practice: (See Score Sheet)

<u>If the child gets two or fewer correct,</u> say, ***Remember, I want you to keep doing the opposite from what I say, but this time, touch your knees and shoulders.***

Proceed to Part II test section. Do not explain any parts of the task again.

Now that you know all the parts, we're going to put them together. You're going to keep doing the opposite from what I say to do, but you won't know what I'm going to say.

There are four things I could say.

> ***If I say to touch your head, you touch your toes.***
>
> ***If I say to touch your toes, you touch your head.***
>
> ***If I say to touch your knees, you touch your shoulders.***

If I say to touch your shoulders, you touch your knees.

Are you ready? Let's try it.

(Administer Part II)

After the child completes the task, say: ***"Thank you for playing this game with me today!"***

HTKS Date ____________________

Name ____________________ Examiner ____________________

Location ____________________ Score ____________________

Part I TRAINING

Retraining

A1. **What do you do if I say "touch your head"?**			
0 (head)	1	2 (toes)	
A2. **What do you do if I say "touch your toes"?**			
0 (toes)	1	2 (head)	

UP TO 3 TIMES TOTAL (A+B)

Part I PRACTICE

B1.	**Touch your head**	0 (head)	1	2 (toes)	Retraining
B2.	**Touch your toes**	0 (toes)	1	2 (head)	________
B3.	**Touch your head**	0 (head)	1	2 (toes)	
B4.	**Touch your toes**	0 (toes)	1	2 (head)	

UP TO 3 TIMES TOTAL (A+B)

Part II TRAINING

Retraining

C1. **What do you do if I say "touch your knees"?**			
0 (knees)	1	2 (shoulders)	

UP TO 3 TIMES TOTAL (C+D)

Part II PRACTICE

D1.	**Touch your knees**	0 (knees)	1	2 (shoulders)	Retraining
D2.	**Touch your shoulders**	0 (shoulders)	1	2 (knees)	________
D3.	**Touch your knees**	0 (knees)	1	2 (shoulders)	
D4.	**Touch your shoulders**	0 (shoulders)	1	2 (knees)	

UP TO 3 TIMES TOTAL (C+D)

Part I (Everyone)

1.	**Head**	0	1	2 (toes)
2.	**Toes**	0	1	2 (head)
3.	**Toes**	0	1	2 (head)
4.	**Head**	0	1	2 (toes)
5.	**Toes**	0	1	2 (head)
6.	**Head**	0	1	2 (toes)
7.	**Head**	0	1	2 (toes)
8.	**Toes**	0	1	2 (head)
9.	**Head**	0	1	2 (toes)
10.	**Toes**	0	1	2 (head)

Total Points ________________

Number of 1 responses ________________

Part II (5 or more correct or Kindergartner)

11.	**Head**	0	1	2 (toes)
12.	**Toes**	0	1	2 (head)
13.	**Knees**	0	1	2 (shoulders)
14.	**Toes**	0	1	2 (head)
15.	**Shoulders**	0	1	2 (knees)
16.	**Head**	0	1	2 (toes)
17.	**Knees**	0	1	2 (shoulders)
18.	**Knees**	0	1	2 (shoulders)
19.	**Shoulders**	0	1	2 (knees)
20.	**Toes**	0	1	2 (head)

Total Points ________________

Number of 1 responses ________________

CURRICULUM VITAE

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Educational Preparation

Ph.D. (2018) Utah State University, Logan, Utah
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Advisor: Ann M. Berghout Austin, Ph.D.
Dissertation: *Comparing the Predictive Power of Executive Function Assessment Strategies on Preschool Mathematics Performance*

B. S. (2005) Brigham Young University, Provo, Utah
Marriage, Family, and Human Development

A. S. (2002) Brigham Young University – Idaho, Rexburg, Idaho
Family Science

Scholarly Interests and Areas of Research

Parent-Child Relationships: Relationship between family stress and the parent-child relationship particularly with regarding to executive function (EF); relationship between perceived (parent) executive function impairment and parent-child relationship; relationship between parenting stress and parent-child activities including enriching educational activities

Early Childhood Cognitive Development: Relationship between early life stress and individual aspects of executive function development; role of home and child care environment on cognitive development; development of early mathematics concepts; child development in the developing world

Academic and Professional Positions

2013 – present Graduate Research Assistant, Department of Family, Consumer, and Human Development, Utah State University with Dr. Ann Austin. Projects: Validation of Care About Childcare, Utah's QRIS; longitudinal study of the development of rural and urban preschool children's math and executive function skills in home and care environments

2015 – 2016	Graduate Instructor, Marriage and Family Relationships, FCHD 2400; two consecutive semesters, average class size: 150; Department of Family, Consumer, and Human Development, Utah State University
Spring 2015	Graduate Teaching Assistant for Kay Bradford, Ph.D.; Parenting and Child Guidance, FCHD 2660; Department of Family, Consumer, and Human Development, Utah State University
2008 – 2013	Classroom teacher; 3rd (2011-2013) and 6th (2008-2011) grade; Firth School District, Firth ID

Professional Memberships & Affiliations

Professional Organizations

Society for Research in Child Development (SRCD)	Member, January 2015 – present
American Psychological Association (APA)	Member, January 2016 – present
Society for Research in Human Development (SRHD)	Member, February 2016 – present
National Council on Family Relations (NCFR)	Member, May 2016 – present
National Association for the Education of Young Children (NAEYC)	Member, February 2018 – present

Scholarly Publications

Refereed Journal Articles

Manuscripts Under Revision

Esplin, J. A., Neilson, B. G., Austin, A. M. B., Fronk, A. *Self-report QRIS: Challenges and validation by center capacity and subsidy rate*.

Esplin, J. A., Blevins-Knabe, B., Austin, A. M. B., Hendershot, S. M. & Corwyn, R. F. *Predictors of early numeracy: Applied measures in two childcare contexts.*

Works In Progress

Esplin, J. A., Neilson, B. G., Austin, A. M. B., Corwyn, R. F., & Blevins-Knabe, B. *Comparing the predictive power of executive function measures and assessment strategies on math performance.*

Neilson, B. G., **Esplin, J. A.,** Corwyn, R. F., Austin, A. M. B., & Blevins-Knabe, B. *Preschool children's development in mathematics and executive function: A rural longitudinal study*.

Scholarly Book Chapters

Hall, K., **Esplin, J. A.**, Larsen, L., Johnson, J., Austin, A. M. B., (In Press). Guarani Mothers and Children: The Impact of the Risk Factors for Poverty. In A. Giralt (Ed.), *Global Mothers in the Twenty-First Century*. Demeter Press.

Esplin, J. A., Neilson, B. G., Austin, A. M. B., Blevins-Knabe, B., Hendershot, S. M., & Loesch, L. A. (2016). Number Line Skills and Home Numeracy Activities for Preschoolers in Center-Based and Family-Based Child Care. In B. Blevins-Knabe & A. M. B. Austin (Eds.), *Early Childhood Mathematics Skill Development in the Home Environment* (pp. 105-126). Springer International Publishing.

Professional Conference Presentations

Esplin, J. A., Neilson, B. G., Austin, A. M. B., Corwyn, R. F., & Blevins-Knabe, B., (2018). *Comparing the predictive power of executive functioning measures and assessment strategies on math performance.* Paper to be presented at the Biennial Conference of the Society for Research in Human Development. March 2018, Plano, TX.

Neilson, B. G., **Esplin, J. A.,** Corwyn, R. F., Austin, A. M. B., & Blevins-Knabe, B. *Preschool children's development in mathematics and executive function: A rural longitudinal study*. Paper to be presented at the Biennial Conference of the Society for Research in Human Development. March 2018, Plano, TX.

Esplin, J. A. (2017). *Maternal Depression and Child Executive Function: Impact at 36 Months*. Poster presented at the annual meeting of the National Council on Family Relations. November 2017, Orlando, FL.

Esplin, J. A., Austin, A. M. B., (2017). *Child Executive Functioning, Family Stress, and the Frequency of Television Use.* Poster presented at the Biennial Meeting of the Society for Research in Child Development. April 2017, Austin, TX.

Esplin, J. A., Austin, A. M. B., (2017). *Parent Stress, Parent Perception of Child Behavior and Provision of Home Numeracy Activities.* A poster symposium presentation at the Biennial Meeting of the Society for Research in Child Development. April 2017, Austin, TX.

Neilson, B., Blevins-Knabe, B., Austin, A. M. B., **Esplin, J. A.**, Loesch, L. A., (2017). *Children's Early Mathematical Development in a Rural Home Numeracy Environment.* A poster symposium presentation at the Biennial Meeting of the Society for Research in Child Development. April 2017, Austin, TX.

Esplin, J. A., Neilson, B. G., Austin, A. M. B., Blevins-Knabe, B., Loesch, L. A. (2016). *Parent and Teacher Rating of Child Executive Functioning.* Poster presented at the Utah State University Student Research Symposium. Student symposium requested and authorized previously reported student research. April 2016, Logan, UT.

Esplin, J. A., Neilson, B. G., Austin, A. M. B., Blevins-Knabe, B., Loesch, L. A. (2016). *Parent and Teacher Rating of Child Executive Functioning.* Poster presented at the Biennial Conference of the Society for Research in Human Development. March 2016, Denver, CO.

Loesch, L. A., Neilson, B. G., Austin, A. M. B., Blevins-Knabe, B., Hendershot, S. M., **Esplin, J. A.**, (2015). *Home Numeracy Environment, Young Children's Executive Functioning, and Performance on the Number Line Tasks.* Poster presented at the Biennial Meeting of the Society for Research in Child Development. March 2015, Philadelphia, PA.

Thompson, B. G., **Esplin, J. A.**, Blevins-Knabe, B., Austin, A. M. B., Hendershot, S. M., (2014). *Correlations of Children's Home Numeracy and Cognitive Abilities*. Poster presented at the Biennial Conference of the Society for Research in Human Development. March 2014, Austin, TX.

Research Experience

Research Assistant for Ann M. Berghout Austin, Ph.D. June 2015 – Present

SUNBEAM Study: A longitudinal study of rural and urban children's mathematical skills and
executive functioning (EF) in home and care environments.

- Co-manager of research study
- Worked on receiving IRB approval
- Selected measures to assess EF, parent-child relationship, and family stress
- Responsible for recruiting, training, and supervising undergraduate and graduate researchers
- Assessed preschool-age children using face-to-face measures
- Scored measures
- Data entry into Excel and SPSS

Research Assistant for Ann M. Berghout Austin, Ph.D. August 2013 – May 2015

Validation of Utah's QRIS

- Obtained inter-rater reliability with Utah's state anchor on the Early Childhood Environmental Rating Scale, Revised Edition (ECERS-R)
- Assessed preschool environments across northern Utah
- Sent and received surveys through Qualtrics
- Data entry into Excel

<u>Research Assistant for Lisa Boyce, Ph.D.</u> August 2013 – May 2015

Child Care Access Means Parents in School grant (CCAMPUS).

- Assessed children and their environments using a variety of measures including:
    - Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4)
    - Woodcock-Johnson, Third Edition
    - Early Childhood Environmental Rating Scale, Revised Edition (ECERS-R)
- Scored measures
- Sent and received surveys through Qualtrics
- Data entry into Excel

Undergraduate Mentoring

Spencer Dutson

- Recruited from FCHD 2400 class to participate in research
- Supervised during summer research practicum
- Hired by department to work for a semester as my undergraduate research assistant
- Trained as research assistant
    - Scored measures and entered data
    - Trained to reliability on four measures
    - Supervised while administering measures to preschoolers

Rhees Johnson

- Recruited from FCHD 2400 class to participate in research
- Hired by department to work for a semester as my undergraduate research assistant
- Trained as teaching assistant
    - Solo taught class lecture/discussion
        - I provided in-depth feedback identifying strengths and areas to improve
    - Trained to give quality feedback on students' assignments
- Trained as research assistant
    - Trained to reliability on four measures
    - Supervised while administering measures to preschoolers

Bonnie Blackburn

- Recruited through department wide email
- Hired by department to work for a semester as my undergraduate research assistant
- Trained as research assistant
    - Trained to reliability on four measures
    - Supervised while administering measures to preschoolers

McKenna Bakker

- Recruited through department wide email
- Trained as research assistant
    - Trained to reliability on four measures
    - Supervised while administering measures to preschoolers

Jamison Bills

- Trained as research assistant
    - Scored measures and entered data

Additional Training/Professional Development & Skills

Utah State University Office of Research and Graduate Studies (GrTS) Training

How Should I Engage an Audience when Presenting Research	November, 2016
How Should I Manage and Store Data Effectively	October, 2016
How Can I Improve My Teaching Techniques	September, 2016
Getting Smart About Posters and Slides	March, 2016
3 Merrill-Cazier Library Resources That Will Make Your Life Easier	February, 2016
How to Design Stunning Posters	March, 2015
How to Create Gorgeous Slides	February, 2015

Utah State University Merrill-Crazier Library

Citation Management Workshop	February, 2017

Grant Writers' Seminars & Workshops, LLC

"Getting Started as a Successful Proposal Writing and Academician"	September, 2016

Utah State University Center for Innovative Design and Instruction (CIDI) Training

How to host and record Adobe Connect interactive web conference meeting	February, 2015
Training in Panopto, Camtasia, and Canvas media	May, 2015
Training for using Canvas for classroom management	May, 2015

Graduate Instructors Forum (GIF)

Bimonthly meeting with faculty member and other graduate instructors were teaching strategies and experiences could be discussed	2015 – 2016

CEHS Office of Research & Statistical Consulting Studio Workshops

Generalized Estimating Equations	February, 2017
Research Electric Data Capture (REDCap)	April, 2017

Extra Statistical Coursework through USU

"R for Health, Behavioral, Education, and Social Scientists" May-June 2017

Academic Awards and Honors

2016 – 2017	William H. and Stella Young Griffiths Scholarship, Family, Consumer, and Human Development, Utah State University ($2,000).
2015 – 2016	Harriet Ann Richards Rasmussen Scholarship, Family, Consumer, and Human Development, Utah State University ($2,000)

Volunteer Service: Student Reviewer for Journals and Conferences

Student Reviewer:

Early Childhood Research Quarterly	2 articles
The Journal of Early Adolescence	2 articles

Conference Proposal Reviews – Student Reviewer:

National Association for the Education of Young Children (2016)

Local Conferences

Utah Council on Family Relations Staff, (April, 2015)

Travel Funding

RGS Graduate Student Travel Award to attend NCFR (2017).
Award total: $300.

Family, Consumer, and Human Development Travel Award to attend NCFR (2017).
Award total: $750.

Society for Research in Child Development Student Travel Award (2017).
Award total: $300.

RGS Graduate Student Travel Award to attend SRCD (2017).
Award total: $300.

Family, Consumer, and Human Development Travel Award to attend SRCD (2017).
Award total: $750.

RGS Graduate Student Travel Award to attend SRHD (2016).
Award total: $200.

Family, Consumer, and Human Development Travel Award to attend SRHD (2016).
Award total: $500