COGNITIVE FLEXIBILITY AND WORKING MEMORY'S LONGITUDINAL PREDICTION OF READING ACHIEVEMENT

by

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To Anna, with love.

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ABSTRACT

Executive function skills have a direct link to reading comprehension (Carretti, Borella, Cornoldi, & De Beni, 2009). Specifically, cognitive flexibility and working memory have been shown as a significant contributor to reading comprehension (Cain, Oakhill, & Bryant, 2004; Cartwright, 2002). Understanding the link between cognitive flexibility, working memory, and reading achievement would allow researchers and educators to identify students in kindergarten who are at risk of reading difficulty. Using the Early Childhood Longitudinal Study, Kindergarten Class of 2010-2011 (ECLS-K: 2011), cognitive flexibility and working memory were investigated to understand if those specific skills at kindergarten were predictive of reading achievement at the end of grade one, two, three, and four using multiple linear regression while controlling for socioeconomic status (SES) and gender. Results showed that working memory and cognitive flexibility were significant predictors for all time points, over and beyond Gender and SES. A second analysis was conducted to analyze the growth of reading achievement, working memory, and cognitive flexibility from kindergarten to fourth grade while investigating if students' SES impacted the slope and intercept of the growth. Results showed that SES impacted the intercept and slope of cognitive flexibility.

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CHAPTER I

INTRODUCTION

The research into executive function has risen dramatically over the past 20 years (Zelazo & Carlson, 2012). Executive function at prekindergarten and kindergarten has been shown to be a predictor for school readiness (Bierman, Nix, Greenberg, Blair, & Domitrovich, 2008; Duncan et al., 2007), math achievement (Brock, Rimm-Kaufmam, Nathanson, & Grimm, 2009; Epsy et al., 2004; McClelland et al., 2007), and reading achievement. (McClelland et al., 2007). Furthermore, students with learning disabilities have been shown to have executive function deficits when compared to their peers (Biederman et al., 2004; Peng, Congying, Beilei, & Sha, 2012; Peng, Sha, Beilei, 2013). Specifically, students with reading disabilities have shown deficits in domain specific working memory (Peng, Tao, & Li, 2013; Swanson, 1993), inhibition (Borella, Carretti, & Pelegrina, 2010; De Beni, Palladino, Pazzaglia, & Cornoldi, 1998), and cognitive flexibility (Helland & Asbjornsen, 2000). While there has been a considerable amount of work investigating the word reading form of reading disabilities and the component skills that support the development of accurate and efficient word recognition (Shaywitz & Shaywitz, 2005), there has been relatively less work investigating the potential factors that facilitate the development of proficient reading comprehension. To address this gap, the current study strives to investigate the role of executive function in the development of reading comprehension across the early school grades.

Executive Function Predicts Future Achievement

Executive function skills develop into adolescence and young adulthood. Huizinga, Dolan, and van der Molen (2006) found that working memory, cognitive flexibility, and inhibition reach their full development between ages 11 and 15, though some specific facets of inhibition continue to mature until young adulthood. A growing body of research shows that executive function is malleable and that interventions to promote these skills should be investigated (Zelazo, Carlson, & Kesek, 2008; Dahlin, 2011; Diamond & Lee, 2011; Zelazo & Carlson, 2012). A review by Diamond and Lee (2011) found that computerized training, exercise, mindfulness, and classroom curriculum have all been shown to increase specific executive function skills.

Children's executive function ability at pre-kindergarten and kindergarten is a predictor for many different skills in school including reading (Bull, Espy, Wiebe, 2008; McClelland, Acock, & Morrison, 2006) and math achievement (Bull et al., 2008; Bull & Scerif, 2001; McClelland et al., 2006). A longitudinal study conducted by McClelland and colleagues (2006) followed students from kindergarten to sixth grade and found that skills in kindergarten predicted math and reading skills between kindergarten and sixth grade. Students with low executive function started kindergarten behind in reading and math, and those same students continued to be behind in academics and executive function throughout their time in the study (McClelland et al., 2006).

Bull and Scerif (2001) found children's executive functions predicted math ability. Additionally, participants with lower math abilities also struggled with inhibition and working memory. In a follow up experiment, Bull and colleagues (2008) found that executive function skills were significantly correlated with both math and reading abilities with the range of correlation between .20 and .55. By the time the participants were 7 and 8 years old, researchers found that visual-spatial working-memory tasks predicted math ability, while reading achievement was predicted by verbal and visual-spatial short term memory.

Theoretical Models of Working Memory and Cognitive Flexibility

Executive function skills allow students to regulate attention and help them to achieve a goal (Diamond, 2013). Executive function is a not unitary construct, but has multiple and separate components (Miyake et al, 2000). These components include cognitive flexibility (also known as shifting), working memory, and inhibitory control (Kieffer, Vukovic, & Berry, 2013; Lehto, Juujarvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000; Zelazo, Blair, & Willoughby, 2016). These cognitive controls are a set of top-down neurocognitive processes that, while they can be categorized as three separate skills, also interact with each other (Miyake et al, 2000; Miyake & Friedman, 2012). Miyake and colleagues (2000) described this as the “unity and diversity” of executive function. While it consists of three entities, the constructs are correlated and work together. Using confirmatory factor analysis with a sample of college students, Mikaye et al. (2000) found cognitive flexibility, working memory, and inhibition to be distinguishable as a three-factor model of executive function.

On the other hand, Anderson (2002) developed a model through a review of previous research that includes cognitive flexibility, goal setting, attentional control, and information processes. Unlike Mikaye’s model, Anderson combined certain facets of executive functions into one umbrella while also creating different execution function groupings. Specifically, Anderson included working memory within the cognitive flexibility domain, inhibition within the attentional control domain, planning within the goal setting domain, while the information processing domain includes fluency and speed of processing. Anderson's model posits that all four domains are interconnected, with attentional control holding the most sway over the other the three domains, but the other three domains are interrelated and interdependent. While there may not be uniform agreement on exactly how executive function is subdivided, there are similarities across various conceptual models.

Moreover, a considerable number of empirical studies support Miyake and colleagues (2000) view of executive function as having three basic domains: working memory, cognitive flexibility, and inhibition (Best & Miller, 2010; Fisk & Sharp, 2004; Huizinga et al., 2006; Lehto et al., 2003; van der Sluis, De Jong, van der Leij, 2007). Miyake's model has been supported by research using broad samples from childhood to late adulthood, and has been replicated with children (Lehto et al., 2003). Using a sample of children between the ages of 8 and 13, Lehto and colleagues (2003) confirmed the three-factor model of executive function. Miyake's model had the best model fit compared to other models of executive function. Fisk and Sharp (2004) found similar results to Miyake's with an adult sample between the ages of 20 and 81 years. Based on these findings, Miyake's model has been confirmed with a wide age group.

Working Memory

Working memory is a multicomponent process in which a limited amount of information is temporarily stored in the mind while manipulating it (Baddeley, 2003). Working memory is a general skill that is used in a variety of domains, including reading (Swanson, Howard, & Saez, 2006). The difference between short term memory and working memory is that there must be some type of interference taking place while temporarily holding the information for it to be considered working memory (Kane & Engle, 2002). Baddeley and Hitch (1974) described working memory as a work place in the mind that has limited storage and processing. They also determined that working memory was a three part process with a main central executive, visuospatial sketchpad, and a phonological loop, with the central executive coordinating all three.

The phonological loop can hold sounds for a limited amount of time before the information is lost. In the loop, rehearsal can be used to keep the information from decaying, but that is also limited in the amount of information it can rehearse (Baddeley, 1996). Phonological input can enter the phonological loop through auditory or visual input (Baddeley, Gathercole, & Papagno, 1998). The visuospatial sketchpad is similar to the phonological loop but instead involves images of objects. It is limited in capacity and can hold up to four objects (Luck & Vogel, 1997). Finally, the central executive receives and gives input to the phonological loop and visuospatial sketchpad. The central executive coordinates prioritizing incoming perceived information, the retrieval of information from long term memory and selective attention across the sensory storage areas in pursuit of goal directed behavior (Baddeley, 1996).

One way working memory is measured is by having participants hold information in their mind while completing an interference task. The ospan task, a working memory measure, has participants read and respond to basic math problems while also introducing them to words. The words will have to be recalled at a later time. The math problems serve as the interference (Kane & Engle, 2000). A way to measure working memory through domain specific tasks includes reading two sentences, asking a comprehension question after each sentence, and then having to repeat the last word in the first sentence (Daneman & Carpenter, 1980).

It has long been hypothesized that working memory supports the comprehension of written language. For example, the capacity theory of comprehension proposed by Just and Carpenter (1980) put forth the importance of individual differences in working memory in comprehending written language. According to the capacity theory of comprehension, working memory supports comprehension by allocating resources for the task of reading comprehension. Reader's individual differences in working memory are shown when completing difficult cognitive tasks. For example, readers use working memory when disambiguating pronouns in a text. A reader must hold previously read information in working memory to integrate the pronoun with its referent. Readers with a smaller working memory capacity will take longer to integrate the pronoun with recent information (Daneman & Carpenter, 1980).

Cognitive Flexibility

Another aspect of executive function is cognitive flexibility, or shifting. Cognitive flexibility refers to being able to view something in multiple or new ways (Zelazo et al.,

2016) and being able to change, or shift, attention between multiple tasks (Miyake et al., 2000). In Zelazo, Blair, and Willoughby's (2016) overview of executive function, they define cognitive flexibility as the ability to think about something in multiple ways, while Anderson (2002) defines flexibility as learning from mistakes, dividing attention, looking for alternative solutions, and taking in information from multiple sources at the same time. While researchers differ on the definition of cognitive flexibility, most consider switching between two separate sets of information quickly to be a defining characteristic of the construct (Anderson, 2002; Miyake et al., 2000).

One way to measure cognitive flexibility is to examine how well someone can switch between multiple sets of knowledge (Anderson, 2002), including disengaging from one task set and then engaging in a different task set effectively (Miyake et al, 2000). Cognitive flexibility is commonly measured through a type of multiple classification card sort task (Cartwright, 2012). Multiple classification tasks ask participants to sort a set of cards based on different characteristics (Cartwright, 2002, 2012; Jacques & Zelazo, 2005; Miyake et al., 2000). After a participant has sorted the cards one way, they must then switch and sort it differently based on new characteristics. These tasks can be general or domain specific. For example, in a reading-specific multiple classification task, measures of flexibility include having students sort cards based on phonological and semantic information (Cartwright, 2002). An analogous example of a domain general task could include sorting pictures based on colors or shapes (Zelazo, 2006).

Cognitive flexibility can be measured by deductive or inductive sorting tasks (Jacques & Zelazo, 2005). Inductive flexibility tasks are not explicit in their directions, instead requiring participants to discover the new rule allowing them to correctly switch between two different perspectives. For example, the Wisconsin Card Sorting Tasks (WCST) has participants sort cards based on shapes and colors and has been shown to effectively measure cognitive flexibility (Miyake et al., 2000). Individuals performing the WCST are expected to switch between different selection criteria (e.g., color, shape) and to switch the criteria used to determine an accurate choice without explicit instructions from the person administering the test. Rather, the respondent is expected to learn from the feedback from the test administrator that the selection criterion has shifted and provided responses based on the new criterion.

In contrast, deductive tasks are explicit in their direction. Participant must follow a certain rule for making selection that is given by the test administrator. For example, the dimensional card change sort (DCCS) is similar to the WCST but uses explicit instructions (Zelazo, 2006). In the DCCS task, the test administrator shows a participant pictures of a familiar object (e.g., rabbit or car) and asks the participant to sort based on specific dimensions (e.g., colors or shape). As participants progress through the task they are instructed to change between the dimensions and continue the sort. Reactions times and errors are measured to determine their flexibility on the task (Zelazo, 2006). DCCS has primarily been used to measure cognitive flexibility in early childhood (Doebel & Zelazo, 2015). Additionally, the Trail Making Test (Delis et al., 2001) has also been repeatedly used to measure cognitive flexibility. For the trail making task, participants are instructed to draw a line connecting 25 points on a page that include letters or numbers. For example, the task may ask the participant to connect points on the page based on alphabetical order (e.g., A, B, C) or to connect numbers in ascending order (e.g, 1, 2, 3). Another measure of the Trail Making Tests asks participants to alternate between letters and numbers (e.g., A, 1, B, 2, C, 3,).

While there is fairly wide support for models of reading that specify the role of general cognitive processes and executive function in reading comprehension, some educators do not have the view that readers need intervention in this area (Spear-Swerling & Sternberg, 1996). Although some studies have shown these processes are resistant to change through training (Melby-Lervag, Redick, & Hulme, 2016), others have found that some facets of executive function are malleable (e.g., Dahlin, 2011). However, only a few studies have examined the malleability of cognitive flexibility. After Cartwright (2002) found that a reading-specific multiple classification task was predictive of reading comprehension, she conducted a second study to investigate a reading specific flexibility intervention to improve reading comprehension of elementary students. For two weeks, participants completed a reading specific flexibility measure with the teacher providing immediate feedback if they completed the task incorrectly. Other students were trained on a non-reading specific flexibility measure (i.e., dots on a page), for two weeks. Reading specific flexibility training improved students’ reading comprehension more than the general flexibility task group and control group. The results demonstrated that cognitive flexibility can be improved and transfer to reading comprehension.

Theoretical Model of Reading Development

Reading develops over time (Chall, 1983; Ehri, 1995; Ehri & McCormick, 1998; Paris, Carpenter, Paris, & Hamilton, 2005). Specifically, reading is acquired through different developmental stages. Ehri's (1995) model has outlined four different development phases for word reading, which include the pre-alphabetic phase, the partial-alphabetic phase, the full-alphabetic phase, and the consolidated-alphabetic phase. The pre-alphabetic phase includes readers who have no knowledge of the alphabetic system. These readers are not familiar with letters and there are no letter sound relationships being used. Readers are interacting with print through visual cues and features. For example, readers in this stage may be able to read the word McDonalds because it is located next to the arches but would not be able to read the word out of context.

As readers reach the partial-alphabetic phase, they are learning basic skills regarding print familiarity and letter recognition. Partial-alphabetic phase readers are learning sounds for some letters. Students are aware that these sounds are part of words and can start to understand the beginning and ending letters of words. At this stage, readers struggle to decode words they do not know because they need context to help them read (Ehri, 1995).

Readers transition into the alphabetic phase when they are able to read words through combining the letters and sounds together (Ehri, 1995). Specifically, readers in this stage understand the phonemes in the words and can easily distinguish between similarly spelled words. The decoding process starts slowly in the phase but continues as the readers become more fluent. This decoding process allows readers to read unfamiliar words without context (Ehri, 1995; Ehri & McCormick, 1998). As the amount of reading increases, readers are quickly increasing their sight word knowledge (Ehri & McCormick, 1998).

The consolidated-alphabetic phase actually begins during the alphabetic phase. Readers are able to use the repeated experience of reading to help with their spelling ability (Ehri, 1995). For example, Ehri uses the example of -EST as a consolidated unit. Once a reader knows this unit, the reader will be able to read nest, pest, and rest. Knowing these consolidated units makes reading easier, and it allows readers to read longer sight words (Ehri, 1995). Readers are able to grow their sight word lexicon after learning these consolidated units. The reader will then progress to a stage where reading is automatic (Ehri & McCormick, 1995). Readers may struggle with new words, but readers have now learned strategies in these four phases to be able identify the word.

Phonemic Awareness

Elementary student's phonemic awareness is predicted of later word reading ability (Hulme et al., 2012; Muter, Hulme, Snowling, and Stevenson, 2004). The National Reading Panel Report (2000) defines phonemic awareness as the ability to single out and manipulate phonemes in spoken words. This ability is assessed in multiple different ways. The following ways were described in the National Reading Panel report: Phoneme isolation, which require readers to identify single phonemes; phoneme identity, which requires the reader to identify common sounds from a variety of words; phoneme categorization, which requires readers to identify the word that sounds different;

phoneme blending, which makes the reader listen to a list of separate sounds and must combine them to a whole word, phoneme segmentation; which requires the reader to count the amount of phonemes in a word; and phoneme deletion, which asks reader to delete a phoneme and say the new word.

Hulme and colleagues (2012) found that letter sound and phonemic awareness are two causes of later word reading difficulty. Without those skills fully developed early on, readers will struggle as they develop. Muter, Hulme, Snowling, and Stevenson (2004) investigated the development of reading skills of 90 British students over the first two years of their schooling. They found that letter identification and phonemic awareness were significantly predictive of later word recognition skills. As readers develop, the skill of being aware of phonemes is paramount to successful word reading.

Vocabulary

A reader's vocabulary is an essential part of understanding the text that is being read. Vocabulary knowledge develops over time and is predictive of later reading comprehension (Paris et al., 2005; Cunningham & Stanovich, 1997). Cunningham and Stanovich (1997) found that 1st grade student's vocabulary on the PPVT significantly predicted reading comprehension ten years later. Additionally, Tabors, Snow, and Dickinson (2001) found that kindergarteners' vocabulary knowledge was significantly predictive of fourth grade reading comprehension. The connection between vocabulary and comprehension is also there for struggling readers. Poor readers can struggle with automatically accessing word meanings when in the process of reading (Perfetti, 1985). This means that comprehension speed is lowered because more resources are working to determine individual word meaning instead of comprehending the text. Intervention in vocabulary has been linked to increases in reading comprehension. In a meta-analysis, Elleman, Lindo, Morphy, and Compton (2009) found that vocabulary intervention increased comprehension, three times more so for struggling readers. Vocabulary knowledge is a necessary skill when measuring reading achievement.

The Cognitive View of Reading Comprehension

Readers need many skills to be successful, including phonological awareness, decoding, fluency, vocabulary, and reading comprehension (Kendeou, van den Broek, Helder, & Karlsson, 2014; National Reading Panel, 2000; RAND Reading Study Group, 2002). Reading comprehension is a complex cognitive process that is an interaction between the text and the reader (National Reading Panel, 2000; RAND Reading Study Group, 2002). A key word in the definition is that comprehension is a cognitive process. These cognitive processes can include working memory, inhibition, sustained attention, cognitive flexibility, mental representations, and inferencing (Georgiou & Das, 2016; Hogan, Bridges, Justice, & Cain, 2011; Kintsch, 1988; RAND Reading Study Group, 2002).

Readers use both working memory and cognitive flexibility to make connections, hold relevant information in their minds, and switch between different reading strategies (Gaskins, 2008). Both of these processes are relied on throughout the process of creating meaning. While working memory is used to hold on to words and meaning until the task of comprehension is completed, cognitive flexibility is used as a mechanism to switch resources as the construction and integrations of meaning are taking place. Readers who are not flexible will not be able to continue the process without creating the most accurate model.

The importance of flexibility is clearly seen when cognitive flexibility is measured when people switch between weak and strong connections while creating meaning (Kintsch, 1988). Readers must be flexible in order to be able to work through the all the connections that have arisen from the connectionist model to determine which model is the strongest. The flexibility must be there to effectively switch, while at the time relying on working memory to continue to keep the models in an active state while all the other processes are taking place. Working memory and cognitive flexibility are an integral part of reading comprehension. Readers use both to make connections, hold relevant information in their mind, switch between decoding words and making meaning, and switch between different reading strategies (Gaskins, 2008). Some researchers suggest that cognitive flexibility is predictive of reading achievement because readers must be able to switch between different strategies (Cole, Duncan, & Blaye, 2014).

The Construction Integration (CI) model lays out a model of reading comprehension that relies on these specific cognitive processes. The CI model provides an account as to how a text representation is formed, elaborated, integrated, and combined with the reader's prior knowledge (Kintsch, 1988). The model uses both top-down and bottom-up processes as they work collaboratively (Kintsch, 2005), and relies heavily on executive function (Kintsch, 2005; Wharton & Kintsch, 1991). The model shows that these representations are constructed through linguistic input, as well as integrating the reader's knowledge with the linguistic input (Kintsch, 1988). Kintsch describes his model as a mixture of connectionist and production system models (Kintsch, 1988), which has an emphasis on working memory and long term working memory (Goldman & Varma, 1995).

The process begins when the reader forms propositions and concepts from the text (Kintsch, 1988, 2005). The actual words on the page, the propositional level, are just a part of surface level memory that is very short term. This temporary memory process will quickly not remember how a certain phrase or sentence was specifically written (Kintsch, 2004). It is the representations that are formed based on the propositional level text that will be remembered, and it will be held in working memory as the next steps in the model take place. At this stage in the construction process, a representation is formed from the input it previously received. An elaboration process takes place by activating a connectionist retrieval process for associated sets of background knowledge from long-term memory. The activation of background knowledge is a bottom-up process (Kintsch, 2005). Inferences are also being made during this elaboration phase, and working memory is holding the representations as inferences are taking place. For example, when the text is incoherent, the reader uses inferences to create a coherent model. Many connections are created during this time, and many of them are inaccurate connections. The model has yet to create a suitable representation to comprehend what has been read. For readers to make inferences, they must be able to recognize something is amiss and switch to conscious inference making.

The integration portion of the model takes the newly activated concepts from the construction phase and works to discards unwanted connections. The goal of the model is to switch from a representation with weak connections to background knowledge to a representation with a stronger and more stable connections. The text is always interacting with representations from background knowledge (Kendeou & O’Brien, 2016). The background knowledge representations that have been activated from the text could still be incorrect. This model requires switching between different representations. This happens when the model inhibits all the inferences that are not relevant to the text. Connections that have been made between propositions input and inferences are strengthened. Model construction is cyclical and the model continuously updates until the incorrect information has been eliminated (Kendeou & O’Brien, 2016). A well-constructed model must be flexible enough to move forward with the strongest connection between the input and knowledge. If the integration process fails, it must start again. Kintsch (1988) stated that if model creation fails, a problem-solving activity may be required to get the integration process started again.

A reader must be able to be able to conclude a problem has arisen and switch over to a problem-solving activity. This is done through comprehension monitoring, which is the ability of the reader to understand inconsistencies in the text (Oakhill, Hartt, & Samols, 2005). Poor readers are not able to identify those inconsistencies (Oakhill et al., 2005). The process of comprehension monitoring develops quickly between first and third grade (LARRC & Yeomans-Maldonado, 2017). Past research suggests that cognitive flexibility may indeed be needed in support of comprehension monitoring. Poor comprehenders have been shown to have a deficit in the area of switching between different reading tasks (Cartwright, 2017) or even have the ability to implement different reading strategies (Gnaedinger, Hund, & Hesson-McInnis, 2016). Taken together, many different cognitive processes are required by the construction-integration process. As the below table shows, the model relies on cognitive processes, including working memory and cognitive flexibility.

Table 1

Cognitive Processes of the CI Model

Cognitive process	Comprehension Activity
Short-term memory	Propositional input
Working memory	Construction, integration, inference making, connectionist retrieval, situational model, problem solving
Long-term memory	Construction with background knowledge
Cognitive flexibility	Integration, integration errors, problem solving

The Role of Executive Function, Working Memory, and Cognitive Flexibility in Reading

Executive function plays a role in reading comprehension (Carretti, Borella, Cornoldi, & De Beni, 2009; Cutting, Materek, Cole, Levine, & Mahone, 2009; Follmer, 2018; Foy & Mann, 2013; Georgiou & Das, 2016; Jacobson et al., 2011; Locascio, Mahone, Eason, & Cutting, 2010; Swanson et al., 2006). Specifically, students with reading comprehension deficits show deficits in executive function (Cutting et al., 2009), and executive function is predictive of later academic achievement (Alloway & Alloway, 2010; Bull et al., 2008; Bull & Scerif, 2001; McClelland et al., 2006).

That is clearly seen when cognitive flexibility is used to switch between weak and strong connections, including different types of inferences, during the integration portion of the model. Readers must be flexible to be able to work through the all the connections that have arisen from the connectionist model to determine which model is the strongest. The flexibility must be there to effectively switch, while at the time relying on working memory to continue to keep the models in working memory while all the other processes are taking place. This can be done consciously through the use of strategies and self-regulation. The seminal work of Pintrich and De Groot (1990) found that middle schoolers were more likely to have better academic performance when they self-regulated their behavior, including the use of comprehension monitoring strategies. Cognitive flexibility is used to implement reading strategies, including when needed to know when to switch to a different strategy (Gaskins, 2008).

Knowing that these process are integral to reading comprehension, can we determine if cognitive flexibility and working memory at kindergarten predict later reading achievement? If working memory and cognitive flexibility in kindergarten is predictive of later reading achievement that will add to the base of literature and open avenues of research into intervention studies with young students entering school.

In support of this view of the role of executive function in support of reading comprehension, past research suggests that cognitive flexibility and inhibition have a direct relationship with reading comprehension (Cartwright, 2002; Gaskin, 2008; Kieffer et al., 2013; van der Sluis, de Jong, & van der Leij, 2004). For example, a path analysis of 120 fourth grade students found that shifting and inhibition were better predictors of reading comprehension than word reading and language comprehension (Kieffer et al., 2013). Readers use inhibition to suppress information that is not central to the text, so they can focus and hold the important information in their mind (Borella et al., 2010). Cognitive flexibility is used to switch between phonological and semantic processes, as well as implementing different comprehension strategies (Berninger & Nagy, 2008; Cartwright, 2002; Gaskins, 2008). Specifically, while investigating the facet of inhibition, participants with a reading disability were found to have weaknesses in response inhibition (Willcutt, Pennington, Olson, Chhanildas, & Hulslander, 2005). These students were found to be at least 1.75 standard deviations behind their peers in a total reading composite score. This shows the relationship between inhibition and reading, both for word reading deficits and comprehension deficits.

Readers need to be able determine which information is needed to understand the text, and inhibition plays a role in that task. For example, when investigating which facets of inhibition readers are weaker on, Borella et al., (2010) found that poor comprehenders did not differ in prepotent response inhibition or response to distractor inhibition, which has been found previously (van der Sluis et al., 2004), but did differ when it came to resistance to proactive interference. Poor comprehenders have also been shown to have difficulties suppressing irrelevant information that is not needed for comprehension (Borella et al., 2010). Previous research found that resistance to proactive interference is connected to working memory (Friedman & Miyake, 2004), in which poor readers have also been shown to have deficits (Carretti et al., 2009). If working memory and cognitive flexibility in kindergarten is predictive of later reading achievement, research examining this topic will be a useful addition to the extant literacy literature and may open avenues of research into intervention studies with young students entering school.

CHAPTER II

LITERATURE REVIEW

Cognitive Flexibility has been shown to be correlated, and predictive, to reading comprehension (Cartwright, 2002). That relationship is being explored to understand if cognitive flexibility at kindergarten can predict reading outcomes later in elementary school. A comprehension search of the literature was completed to understand the link between cognitive flexibility and reading comprehension. An electronic search of PsycINFO was completed with the terms cognitive flexibility AND reading. The search came up with 212 results. In addition to the electronic search, reference sections of those included studies were reviewed. All abstracts from the electronic and reference search were reviewed.

The four inclusion criteria used during this search included (1) studies measuring cognitive flexibly, or shifting, which requires participants to change and implement rules in a task; (2) the flexibility data must be on its own and not combined with other executive function skills; (3) cognitive flexibility must be compared to reading achievement; (4) participants must be in Pre-k through 12th grade. Studies with participants with autism spectrum disorder were excluded to avoid confounding differences in reading and cognitive flexibility. After reviewing abstracts, 35 articles were pulled to review and 16 studies were not included in this review because they did not meet all four of the search criteria (e.g., many of the studies did not measure cognitive flexibility). Sixteen studies were included in this review (See Table 1).

Table 2

Results From the Search Criteria

Study	Age/Grade	Sample Size	Intervention	Length of Time	Results
Bierman et al., (2008)	4 years olds	356	No	6 months	Pre-k student's score on a cognitive flexibility measure predicted their acquisition of pre-emergent literacy skills.
Cantin et al., (2016)	7 to 10 year olds	93	No	One session	Cognitive flexibility contributed to reading comprehension.
Cartwright, (2002) Study 1	7 to 11 year olds	44	No	One session	Reading specific flexibility made contributions to comprehension
Cartwright, (2002) Study 2	7 to 11 year olds	36	Yes	Two weeks of intervention	Intervention on reading specific cognitive flexibility improved reading comprehension.

Table 2 (continued)

Study	Age/Grade	Sample Size	Intervention	Length of Time	Results
Cartwright et al., (2017) Study 1	1st & 2nd graders	48 students. 24 with reading comprehension deficits (RCD) and 24 matched control	No	One session	Students with RCD had deficits in cognitive flexibility. Students with RCD were not able to switch between phonological and semantic aspects of reading
Cartwright et al., (2017) Study 2	1st & 2nd graders	39 students. 18 with RCD and 21 matched control	Yes	One per week for five week	Students in intervention with RCD improved on reading comprehension measure after intervention.
Cartwright, Marshall, Dandy, & Isaac (2010)	1st & 2nd graders	64	No	One session	Reading specific flexibility task performance predicted reading comprehension.

Table 2 (continued)

Study	Age/Grade	Sample Size	Intervention	Length of Time	Results
Cole, Duncan, & Blaye (2014)	2nd graders	60	No	One session	Cognitive flexibility predicted reading comprehension beyond the influence of word reading.
Gnaedinger, Hund, Hesson-McInnis (2016)	2nd through 5th grade	74	No	One session	Cognitive flexibility predicted comprehension. Students with deficits in cognitive flexibility struggled in implementing reading strategies.
Guajardo & Cartwright (2016)	3 to 5 year olds	31	No	Two sessions over a three year time period	Cognitive flexibility at preschool predicted contributed to reading in elementary school.
Kieffer, Vukovic, & Berry (2013)	4th graders	120	No	One session	Cognitive flexibility made direct and indirect contributions to reading comprehension.

Table 2 (continued)

Study	Age/Grade	Sample Size	Intervention	Length of Time	Results
Latzman, Elkovitch, Young, & Clark (2010)	11 to 16 year old males	151	No	One session	Cognitive flexibility significantly predicted reading comprehension.
Monette, Bigras, & Guay (2011)	Kindergarten students	85	No	Two sessions over a year and a half. EF measured at winter of K and reading at end of 1st grade.	There was no relationship between kindergarten cognitive flexibility and first grade reading achievement.
Nouwens, Groen, & Verhoeven (2016)	9 to 12 years old	117	No	One session	Cognitive flexibility contributed to reading comprehension when controlling for working memory.
Reiter, Tucha, & Lange (2005)	Mean age of 10.8	82 – 42 with dyslexia and 42 matched control	No	One session	Students with dyslexia did not show a difference in cognitive flexibility compared to students without.

Table 2 (continued)

Study	Age/Grade	Sample Size	Intervention	Length of Time	Results
Roberts, Norman, & Cocco (2015)	3rd graders	156	No	One session	Reading specific cognitive flexibility correlated to reading comprehension.
Van der Sluis, de Jong, & van der Leij (2004)	4th & 5th graders	74	No	One session	Reading disabled students, as measured through reading fluency, did not show a difference in cognitive flexibility.
Van der Sluis, de Jong, & van der Leij (2007)	4th & 5th graders	172	No	One session	Cognitive flexibility was negatively correlated with reading ability as measured through fluency.
Yeniad, Malda, Mesman, van IJzendoorn, & Pieper (2013)	Children	16 studies, 2266 participants	N/A	N/A	Students with a higher cognitive flexibility capacity showed better performance in reading.

Note: RCD =reading comprehension deficits, EF = executive function

Flexibility is used when switching from the decoding process to switching to the process of constructing meaning of words and sentences (Berninger & Nagy, 2008; Cartwright, 2002; Cartwright et al, 2017). Cartwright and colleagues (2017) found that elementary students with reading comprehension deficits also had deficits in their cognitive flexibility. Readers with comprehension deficits were inflexible and focused only on decoding and did not make the switch to meaning.

Cognitive Flexibility and Reading Comprehension

Cognitive flexibility has been measured through classification tasks, which is done through asking participants to sort cards based on certain rules. The rules are then changed and the participants must sort the cards in a different way. The change in the rules is considered the switching task, and reaction time and errors are used to calculate the flexibility of the participant. Flexibility can be measured either through a domain general task, like the WCST, or a reading specific task (Cartwright, 2002). Cartwright (2002) created a reading specific flexibility task that asked participants to sort lists of words based on phonemes or by word meaning. This task requires participants use reading skills, while domain general tasks do not require reading skills. Cartwright (2002) found that the reading specific flexibility task was a better predictor of reading comprehension than the domain general task. Specifically, the reading task was more predictive of reading comprehension than linguistic comprehension, decoding skills, or even the general domain flexibility.

Roberts, Norman, and Cocco (2015) also found a significant correlation between the two, while Kieffer et al., 2013 found the task was predictive in fourth grader's reading comprehension more so than traditional skills like decoding and linguistic comprehension. Roberts and colleagues (2015) found that cognitive flexibility, measured through a reading specific flexibility measure, was significantly correlated to comprehension. Using the domain general WCST, Kieffer et al., (2013) found that cognitive flexibility made a significant contribution to reading comprehension with fourth grade students. Specifically, cognitive flexibility made contributions over the contributions of language comprehension, word reading, working memory, processing speed, and phonological awareness.

Struggling Readers and Cognitive Flexibility

As mentioned earlier, cognitive flexibility has also been found to play a role in those with a specific reading comprehension deficit (Cartwright et al., 2017; Cole et al., 2014). After measuring a matched sample of first and second graders with and without a reading comprehension deficit, Cartwright and colleagues (2017) found that those with a reading deficit were less cognitively flexible than peers with no deficit. Specifically, they found that readers with deficits had a hard time switching between phonological and semantic processes when reading. On the other hand, other studies have found students with a word reading deficit to have no deficits in cognitive flexibility (van der Sluis et al., 2004**).** Van der Sluis and colleagues (2004) used a one minute reading fluency measure to track words read correctly but did not use a reading comprehension measure. Again, using a reading fluency measure, the same team found that cognitive flexibility was negatively correlated with word reading ability (van der Sluis, de Jong, & van der Leij, 2007). Specifically, they found that as readers become more fluent, they had slightly lower flexibility performance on a battery of shifting measures.

Reiter, Tucha, and Lange (2004) investigated the differences between students with dyslexia and those without dyslexia. They found mixed results with three measures of cognitive flexibility, including the Trail Making Test (Reitan & Wolfson, 1992), the Modified Card Sort Task, a shorter, alternative version to the WCST, (Nelson, 1976), and a flexibility subtest from the Test for Attentional Performance (Zimmerman & Fimm, 1993). Students with dyslexia showed no differences compared to their peers on the card sort task or the trail making test. With the flexibility task, which required a card sort, students with dyslexia showed no difference in reaction time but had significantly more errors compared to their peers (Reiter et al., 2004). Students who have word reading deficits showed no reaction time differences, but did have more errors than those students who have adequate word reading ability. The findings indicated that readers with word reading deficits may have difficulty correctly switching on some flexibility tasks.

Having deficits in cognitive flexibility may limit a student’s ability to effectively implement strategies which could be a reason why students with deficits in cognitive flexibility also have deficits in reading comprehension. Gnaedinger et al., (2016) found that those with weak cognitive flexibility were not as able to implement reading strategies, even if they have the same information about the strategies as other readers.

Students with deficits in flexibility increased their cognitive load to properly implement reading strategies but may not be able to complete other parts of the task. It may be that these students have difficulty implementing reading strategies flexibly due to an increased cognitive load, leaving them without the resources needed to make meaning of text, answer questions, or make inferences. Specifically, Perfetti's (1985) Verbal Efficiency Model suggests that a person's reading ability is based on how many resources they can allocate to a specific reading task. The model states that reading is like an assembly line and all pieces must work together. If a certain process is not working properly, it will impact reading altogether. As Gnaedinger and colleagues (2016) findings suggest, readers with deficits in cognitive flexibility may not able to implement reading strategies because they did not have enough resources to implement strategies and to comprehend the text.

While readers with comprehension deficits show a deficit in cognitive flexibility, a reader's flexibility is a predictor to reading comprehension in both preschoolers and school aged students (Cantin et al., 2016; Cartwright, Marshall, Dandy, & Isaac, 2010; Cole et al., 2014; Folmer, 2018; Guajardo & Cartwright, 2016; Kieffer et al., 2013; Latzman, Elkovitch, Young & Clark, 2010; Morgan et al., 2016; Nouwens, Groen, & Verhoeven, 2016; Yeniad, Malda, Mesman, van IJzendoorn, & Pieper, 2013). In a meta-analysis, Yeniad and colleagues (2013) found that students with a better capacity to switch between tasks performed better on reading tasks. Specifically, they found a moderate relationship between higher level performance on switching tasks and reading tasks. Additionally, Follmer's (2018) meta-analysis found a significant relationship between cognitive flexibility and reading comprehension with an effect size of 0.39.

Development of Cognitive Flexibility

Cognitive flexibility begins to take shape between the ages of 2 and 5 (Deak, 2003; Zelazo, Muller, Frye, & Marcovitch, 2003). In their monograph on the development of executive function, Zelazo and colleagues show that 3 and 4 year olds consistently have difficulty switching between different tasks and perspectives, as measured on the Dimensional Card Change Sort (DCCS) task. The onset and development of cognitive flexible is rapid during the preschool years. Deak posits that the development of cognitive flexibility is in conjunction with the development of language. Specifically, cognitive flexibility is growing as children experience more variability in regards to locations, tasks, and more, all the while talking about the tasks verbally. At the same time children understand the use of rules (e.g., if red, then). Children start to understand and comprehend one rule at age three (Zelazo et al., 2003). By five, they understand multiple rules at the same time, and thus, have expanded their flexibility. As children become older and expand their flexibility, the link between flexibility and continues to be clear.

For example, in prekindergarten students, cognitive flexibility has been found to be predictive with students learning skills necessary to read. Three hundred and fifty students in the federal Head Start pre-k program for low income students had their cognitive flexibility measured using the Dimensional Change Card Sort (DCCS) task

(Zelazo, 2006). The students' cognitive flexibility predicted their acquisition of emergent literacy skills at the end of their prekindergarten year (Bierman et al., 2008). Cognitive flexibility at prekindergarten also has been shown to predict reading comprehension years down the road. Cognitive flexibility in typically developing French sample significantly explained 10 percent of variance, over and above the contributions of semantic and phonological skills, for reading comprehension (Cole et al., 2014). Cole and colleagues (2014) also found that cognitive flexibility predicted isolated word reading when controlling for decoding skills.

Thirty-one students were tracked from prekindergarten to three years later when they were in elementary school (Guajardo & Cartwright, 2016). Cognitive flexibility, as measured through a card sort in prekindergarten students, made significant contributions to reading comprehension in elementary school (Guajardo & Cartwright, 2016). Additionally, the students' cognitive flexibility assessed in elementary school also gave a significant contribution to the students' reading comprehension. Although this study established a link between CF and literacy for young readers, it was limited by the use of a small sample (*n* =31). A larger sample would increase the power of the study and allow for replications of the findings.

Tracking a student's cognitive flexibility over time allows researchers to view how flexibility can predict later reading achievement. Using the Early Childhood Longitudinal Study – Kindergarten Cohort of 2011 (ECLS-K: 2011), Morgan and colleagues (2016) investigated whether cognitive flexibility at kindergarten could predict reading achievement in first grade. The ECLS-K: 2011 database includes over 18,000 children and includes data from a total of four data collection points, two in kindergarten and two in first grade. When controlling for socioeconomic status, self-regulation, and prior reading difficulties, cognitive flexibility significantly predicted students' reading ability at the end of first grade.

On the other hand, Monette, Bigras, and Guay (2011) found no connection between kindergarten flexibility and first grade reading ability. Eighty-five kindergarten students were measured in flexibility mid-way through kindergarten and at the end of first grade. Flexibility was measured through a variety of measures including a card sort task. There was no relationship between cognitive flexibility and reading ability as measured through the Wechsler Individual Achievement Test – Second edition (WIAT-II; Wechsler, 2005). Cognitive flexibility was not alone in not being connected to reading achievement. Working memory and inhibition were also not found to directly correlate to reading achievement. However, this may be due to the fact that while they used a wide variety of measures, the authors reported that they used measures that would quickly measure executive function instead of measuring them "adequately and thoroughly" like they would have liked. The authors believe that their reading measures at first grade did not rely on the use of executive function. For example, the reading measure was heavily reliant on single word reading.

Cognitive flexibility has also been shown to be predictive with students later in childhood and into adolescence (Cantin et al., 2016, Latzman et al., 2010; Nouwens et al., 2016). Cantin and colleagues (2016) found that, in 7 to 10 year olds, cognitive flexibility as measured by the DCCS was a significant predictor of reading comprehension. Nouwens, Groen, and Verhoeven (2016) found similar results with Dutch 5th graders. Using a Dutch reading assessment, they found that cognitive flexibility as measured through the Trail Making Task made unique contributions to reading comprehension. Latzman and colleagues (2010) investigated cognitive flexibility with students between 11 and 16 years old and found similar results. They found that cognitive flexibility predicted reading comprehension, though they used different measures than the literature typically uses to measure cognitive flexibility. They included a single sorting measure from the Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001). Latzam et al (2010) found that cognitive flexibility uniquely explained performance on the reading subtest of the Iowa Tests of Basic Skills.

Malleability of Cognitive Flexibility

Cartwright et al. (2017) demonstrated that cognitive flexibility training can improve comprehension in those with a specific reading comprehension difficulty. Cartwright and colleagues found that a cognitive flexibility training, given once a week for five weeks to students with deficits, significantly improved their reading comprehension. Using the response to intervention framework, the cognitive flexibility training was given through Tier 2 intervention in a 10 minute lesson on the reading specific classification task. As previously done in Cartwright (2002), the intervention trained participants on a reading specific task with immediate feedback from the teacher.

For example, the interventionist would ask a student to sort four words into different sides of a matrix based on different characteristics. After the words were sorted, the students would have to sort the words differently to match a new set of rules. If the student made an error, the interventionist would give immediate feedback. This was repeated over time as an intervention. The intervention, completed in the second half of the school year, doubled the growth of reading comprehension than the previous semester's intervention. The results showed that cognitive flexibility training may transfer to reading comprehension growth and may be an important factor to monitor in early schooling.

Working Memory and Reading Comprehension

Working memory, another aspect of executive function, is used during reading as the reader holds multiples pieces of input together to form meaning (Daneman & Carpenter, 1980). Cain, Oakhill, and Bryant (2004) found that working memory explains unique variance in reading comprehension of readers between the ages of 8 and 11, even when controlling for word reading ability. Working memory capacity can also be predictive of literacy achievement. Alloway and Alloway (2010) found that working memory at age 5 was a predictor for literacy achievement 6 years later. Working memory predicted reading comprehension for French fourth graders when controlling for vocabulary and decoding (Seigneuric, Ehrlich, Oakhill, & Yuill, 2000). Working memory deficits are one cause that leads to a specific reading comprehension deficit (Carretti et al., 2009). Readers with reading comprehension deficits performed worse on working memory measures than their peers who were labeled as good comprehenders (Borella et al., 2010).

Unlike studies which have found that cognitive flexibility can be increased and can transfer to comprehension, a recent meta-analysis found that working memory training did not generalize to skills such as word reading and reading comprehension (Melby-Lervag et al., 2016). While they did find weak evidence that showed reading comprehension transfer effects for working memory immediately following the intervention, the results were not sustained at follow up. Limitations were found in the reading intervention studies, including that control group participants decreased in reading comprehension during the intervention phase, which assisted in the larger increase of the intervention group.

While their meta-analysis showed that reading comprehension was not improved (Melby-Lervag et al., 2016), other studies have shown that training working memory improved reading ability in children (Dahlin, 2011; Garcia-Madruga et al, 2013; Karbach, Strobach, & Schubert, 2015; Loosli, Buschkuehl, Perrig, & Jaeggi, 2011). Specifically, children between the ages of 9 and 11 improved in their reading ability following a two-week working memory training program (Loosli et al., 2011). The same result was found with children between the ages of 7 and 9. After 14 sessions of working memory training, the participants improved in their reading ability, which included listening comprehension, reading comprehension, decoding, and recoding (Karbach et al., 2015). Children with learning disabilities improved their reading comprehension after a working memory intervention (Dahlin, 2011). When specifically looking at younger children, a working memory intervention that improved working memory also improved a composite of early literacy skills, which include print awareness, phonological awareness, alphabet knowledge, and listening comprehension (Rojas-Barahona, Forster, Moreno-Rios, & McClelland, 2015).

SES and Executive function

Students who are born in poverty come to school missing the necessary skills compared to non-impoverished students (Duncan et al., 2007; Fitzpatrick, McKinnon, Blair, & Willoughby, 2014). When measuring the working memory and cognitive flexibility of children from 60 families, Sarsour et al. (2011) found that student's SES was significantly correlated with cognitive flexibility (0.40) and working memory (0.30). Specifically, the family's SES explained 5% of the variance of the student's cognitive flexibility. Six year olds who were in a high SES group performed better on the cognitive tasks compared to the six year olds who were rated in a low SES group (Mezzacappa, 2004). Expanding this research to look from kindergarten to second grade, Little (2017) found significant differences in executive function based on student's socioeconomic status. Using the ECLS-K: 2011 database, Little found significant differences in executive function between the top SES quintile and the lowest, with the higher SES group having scores one standard deviation higher in executive function compared to the lowest SES group. On the other hand, some studies have found that SES does not predict execution function (Noble, Norman, & Farah, 2005). When Noble, Norman, and Farah

(2005) added SES as a predictor of executive function, they found that SES only accounted for 7% of the variance and was not a significant predictor.

Purpose of Study

Research has shown a link between cognitive flexibility and working memory with reading comprehension (Cartwright, 2002; Cole et al., 2014; Guajardo & Cartwright, 2016; Nouwens et al., 2016; Roberts et al., 2015). The predictive power of executive function has been shown for preschool students (Bierman et al., 2008; Guajardo & Cartwright, 2016), elementary students (Cantin et al., 2016; Monette et al., 2011), as well as older students (Latzman et al., 2010). Prior research has indicated that working memory and cognitive flexibility can predict reading comprehension a year or two later (Morgan et al., 2016) while others have found no connection (Monette et al., 2011). More needs to be understood about the predictive power of working memory and cognitive flexibility over time.

The purpose of this study is to investigate if cognitive flexibility as measured by the DCCS can predict reading comprehension four years later. There is a lack of longitudinal research using extant databases that look at these variables for this amount of time. To our knowledge, this is the only study to examine cognitive flexibility’s impact on reading achievement from kindergarten until fourth grade. It’s important to understand how variables at kindergarten impact students at the end of elementary school. Longitudinal data, like ECLS-K:2011, allow investigations into the change over time between cognitive skills and reading achievement. Establishing a link between kindergarten cognitive flexibility and working memory could allow future identification of students at a young age who may need early intervention. More also needs to be known about the gaps in executive function between economic groups (Little, 2017; Sarsour et al, 2011). As Little found in the ECLS-K:2011 database, there are gaps between groups, and this study will further explore the relationship between working memory, cognitive flexibility, and SES. Specifically, will predictions based on working memory and cognitive flexibly differ based on the economic status of the students? That would provide helpful information to researchers who are developing identification tools and interventions for those students with deficits in cognitive flexibility and working memory.

Research Questions

1. How much does cognitive flexibility and working memory at kindergarten contribute to reading achievement, beyond gender and SES, at the end of first, second, third, and fourth grade?
2. How much does cognitive flexibility and working memory at kindergarten contribute to reading achievement at the end of first, second, third, and fourth grade when controlling for interaction effects with SES?
3. Using latent growth analysis, what is the impact of working memory and cognitive flexibility at kindergarten on the intercept and slope of reading achievement from kindergarten until fourth grade?

4. Using latent growth analysis, what is the change over time of working memory from kindergarten to fourth grade?
5. Using latent growth analysis, what is the change over time of cognitive flexibility from kindergarten to fourth grade?

CHAPTER III

METHODOLOGY

Participants

The Early Childhood Longitudinal Study, Kindergarten Class of 2010-11 (ECLS-K:2011) were analyzed. ECLS-K:2011 began collecting data with kindergarten students in the 2010-2011 cohort. Data were available from kindergarten until fourth grade. Data collection took place twice a year for kindergarten through second grade and once a year for third and fourth grade. A total of eight data points were collected.

The participants from ECLS come from a representative sample of the United States population during starting in the 2010 – 2011 school year. A subsample from followed for additional two time points. That subsample was used, and only participants with no missing data was used in this study. The total sample is the present study is 3126 participants. In kindergarten, all participants were measured in the fall and spring. For the rest of the study, students were only measured each spring. Starting in the first grade, a subsample was measured each fall for first and second grade. The fall subsample was also measured with the rest of the sample each spring. The subsample was created so that it was still a representative sample compared to the full sample. The subsample was used to gain access to more data to measure the growth over time. Third and fourth grade was only measured in the spring for the full and subsample. Fall of third grade and fall of fourth grade had no data for any participants. Table 3 reports the demographics for the participants.

A chi square test was completed to determine if the subsample used in the present study was similar to the whole subsample that was used in ECLS. The third time point, which was when the subsample started, was used as a comparison. First, the chi square test was completed to compare the gender makeup of the full subsample and the present study subsample. The analysis revealed that the two samples are similar (χ^2=.593, p = .463). An additional analysis was completed to investigate if the ethnicity of the groups were different. The analysis revealed that the two samples are similar (χ^2=46.202, p = .954). This means that the present study subsample is similar to the original ECLS subsample.

Table 3

Demographic Characteristics of ECLS Participants (N = 3126)

	N	%
Gender		
Male	1628	52.1
Female	1498	47.9
Ethnicity		
Black	282	9.0
White	1298	41.5
Hispanic	1144	36.6
Asian	208	6.7
Native Hawaiian	11	0.4
American Indian	57	1.8
Two or more	125	4.0

Measurement

Cognitive Flexibility. Cognitive flexibility was measured through the Dimensional Change Card Sort (DCCS) task (Zelazo, 2006). The DCCS tasks ask participants to sort 22 picture cards of a familiar object, like a rabbit or car, based on specific dimensions (e.g., colors or shape). The participants are then instructed to change between the dimensions and continue the sort. For example, a group of cards could have a red boat, a blue rabbit, and a red rabbit. The first round, the color game asked participants to sort cards based on color. If students scored high enough, the participants moved to the Shape Game, where the cards were sorted based on the shape. If scored high enough then, the participants moved to the Board Game, where cards were sorted based on if the cards had a black border around the card. Zelazo and colleagues (2014) reported a reliability coefficient of .92 with children between the ages of 3 and 15.

Cognitive flexibility was measured at all time points. Scores are reported for pre-switch (Color Game), post-switch (Shape Game), boarder game, and a combined score. The combined score is a recommended score to use. Physical cards were used for kindergarten and first grade. A computer program was used from second to fourth grade.

Working Memory. Working memory was measured through the Numbers Reversed subtest of Woodcock-Johnson III Tests of Cognitive Abilities (WJ-III; Woodcock, McGrew, and Mather 2001). The Numbers Reserved subtests required participants to temporarily store numbers and recode them and repeat those same numbers backwards. The maximum number of items that could be given to participants were 30 (5 two-digit number items; 5 three-digit number items; 4 four-digit number items; 4 five-digit number items; 4 six-digit number items; 4 seven-digit number items; and 4 eight-digit number items). The participants were rated as either correct, incorrect, or not administered because the participant did not make it that far in the assessment. This was measured after the DCCS task was given. This subtest has a reliability coefficient of .87 where measured on school-aged students (Schrank, McGrew, Woodcock, 2001).

Reading Assessment. Students were given a reading assessment during each data collection time period for a total of eight times. The reading assessment included basic reading skills, vocabulary, and reading comprehension. Specific basic reading skills assessed included letter recognition, word recognition, print familiarity, beginning and ending word sounds, and rhyming words. Reading comprehension was assessed through asking questions that were specifically stated in the text and inference questions. The students would begin with a routing assessment that would determine if the student would take a low, middle or high difficulty reading assessment. Reading achievement scores are reported by using IRT-based scores. Each reading collection point had a reliability between 0.91-0.95. To ensure validity of the reading measures, ECLS-K:2011 took the NAEP Reading Framework of 2009, along with basic reading and vocabulary skills, and created a measure with the help of panel of experts (Tourangeau et al., 2017).

Socioeconomic Status. The socioeconomic status (SES) variable was created for each household through parent interviews during the first year of the study. It was not measured again, and that SES score during the first year was used as the measure of SES. The SES variable was completed by combining the occupation prestige score, income, and education into a formula to find the family's SES. The occupation prestige was completed by taking the self-reported job of the parents or guardians and comparing it to the prestige created from the 1989 General Social Survey. These same prestige scores are still in use today. The scores are ranged from negative numbers (e.g., unemployed, retired, disabled) to the highest score of 53.50 for family members who were executives, administrators, and managerial operators. That prestige score is determined from a formula that also included the income and family's education to create a composite score.

CHAPTER IV

RESULTS

Overview

Data from the ECLS-K:2011 were analyzed using two different statistical processes. The first analysis explored if working memory and cognitive flexibility at kindergarten significantly predicted reading achievement at the end of first, second, third, and fourth grade while controlling for gender and socioeconomic status (SES) using multiple linear regression. An additional multiple linear regression was completed as above, but also examined the interaction terms of working memory*SES and cognitive flexibility*SES. The other type of analysis completed was latent growth modeling. Growth modeling was utilized to determine if working memory and cognitive flexibility impacted the slope and intercept of reading achievement growth from kindergarten until fourth grade. Additionally, growth modeling was used to investigate change over time for both working memory and cognitive flexibility.

Descriptive Statistics. Table 4 reports the observed means and standard deviations for the reading achievement IRT scores at each of the eight time points, Table 5 reports the same information for working memory, Table 6 for the first four time points of cognitive flexibility, and Table 7 has the information for the last four cognitive flexibility time points. Socioeconomic status had a mean of 0.06 and a standard deviation of 0.83.

Table 4

Sample IRT Means and Standard Deviations for Reading Achievement, Working Memory, and Cognitive Flexibility Measures for Kindergarten through Fourth Grade (N = 3126)

Time	Reading M (SD)	Working Memory M (SD)	Cognitive Flexibility M (SD)
Fall K (T1)	-0.50 (0.84)	432.88 (30.10)	14.24 (3.23)
Spring K (T2)	0.47 (0.75)	449.72 (30.06)	15.36 (2.52)
Fall 1st (T3)	0.90 (0.76)	458.53 (27.44)	15.86 (2.24)
Spring 1st (T4)	1.62 (0.73)	470.19 (24.70)	16.23 (2.10)
Fall 2nd (T5)	1.85 (0.65)	474.92 (22.76)	6.41 (1.38) [a]
Spring 2nd (T6)	2.22 (0.63)	481.96 (21.44)	6.96 (1.12) [a]
Spring 3rd (T7)	2.60 (0.64)	490.63 (20.65)	7.24 (1.21) [a]
Spring 4th (T8)	2.90 (0.61)	497.69 (20.25)	7.67 (0.91) [a]

Note: T1= fall kindergarten, T2 = spring kindergarten, T3 = fall first grade, T4 = spring first grade, T5 = fall second grade, T6 = spring of second grade, T7 = spring of third grade, T8 = spring of fourth grade; [a] Starting at T5, the measure used for cognitive flexibility changed. T1-T4 cannot be compared to T5-T8.

Multiple Linear Regression. Multiple linear regression was used because of the interest in examining the impact of Working Memory (WM) and Cognitive Flexibility (CF) on reading achievement. This was done by comparing the standardized beta weights. These weights show the impact that the measures had in a standard deviation unit for every standard deviation change in the predictor. Before conducting the regression analyses, a check for violations of assumptions were made. These checks included assumptions of linearity, homoscedasticity, normality, and independence (Myers, Well, & Lorch, 2010). No violations were found. A multiple regression analysis was conducted to evaluate how well gender, SES, kindergarten WM, and kindergarten CF predicted reading achievement at the end of first, second, third, and fourth grade.

The first analysis was completed to understand how CF and WM impacted reading achievement above and beyond SES and gender. Looking at end of first grade reading achievement, the first model included only gender and SES as predictors. The model explained 17.9% of the variance $F(2, 3123) = 341.48$, $p < .001$. When CF was added to the model, an additional 3.9% variance was explained, which was statistically significant, $F(1,3122) = 156.63$, $p < .001$. For the third model, WM was added to the model, creating an overall model. The addition of WM explained an additional 13.6% of variance, which was significant, $F(1,3121) = 659.64$, $p < .001$. In total, the model that contained gender, SES, CF, and WM explained 35.5% of variance. Specifically, WM and CF explained 17.5%. Results are reported in Table 5.

The same process was also completed for end of second, third, and fourth grade. Looking at end of second grade reading achievement, the first model that included gender and SES as predictors explained 19.3% of the variance $F(2, 3123) = 372.30$, $p < .001$. When CF was added to the model, an additional 3.7% variance was explained, which was statistically significant, $F(1,3122) = 148.55$, $p < .001$. For the third model, WM was added to the model and explained an additional 11.7% of variance, which was significant, $F(1,3121) = 559.69$, $p < .001$. In total, the model that contained gender, SES, CF, and WM explained 34.6% of variance. Specifically, WM and CF explained 15.4% of the variance.

Looking at end of third grade reading achievement, the first model that included gender and SES as predictors explained 19.4% of the variance $F(2, 3123) = 376.73$, $p < .001$. When CF was added to the model, an additional 4.1% variance was explained, which was statistically significant, $F(1,3122) = 166.07$, $p < .001$. For the third model, WM was added to the model and explained an additional 11.7% of variance, which was significant, $F(1,3121) = 564.38$, $p < .001$. In total, the model that contained gender, SES, CF, and WM explained 35.1% of variance. Specifically, WM and CF explained 15.8% of the variance.

Finally, end of fourth grade reading achievement was investigated. The first model that included gender and SES as predictors explained 18.2% of the variance $F(2, 3123) = 347.32$, $p < .001$. When CF was added to the model, an additional 2.7% variance was explained, which was statistically significant, $F(1,3122) = 107.83$, $p < .001$. For the third model, WM was added to the model and explained an additional 10.4% of variance, which was significant, $F(1,3121) = 473.62$, $p < .001$. In total, the model that contained gender, SES, cognitive flexibility, and working memory explained 31.3% of variance. Specifically, WM and CF explained 13.1% of the variance.

The next analysis investigated interaction effects of SES, working memory, and cognitive flexibility. The three predictors were centered, and working memory and cognitive flexibility were separately multiplied by SES to create an interaction variable (e.g., SES*Working Memory & SES*Cognitive Flexibility).

Table 5

Standardized Regression Coefficients for Regression Model of Reading Achievement

	Time 4		Time 6		Time 7		Time 8	
	Beta	R^2	Beta	R^2	Beta	R^2	Beta	R^2
Model 1		.179		.193		.194		.182
Gender	.088		.111		.122		.079	
SES	.416		.426		.425		.420	
Model 2		.219		.229		.235		.209
Gender	.083		.106		.117		.075	
SES	.375		.386		.384		.386	
CF	.202		.196		.206		.169	
Model 3		.355		.346		.352		.313
Gender	.072		.097		.107		.066	
SES	.247		.268		.265		.274	
CF	.107		.108		.118		.086	
WM	.408		.379		.379		.357	

Note: All predictors were statistically significant at each occasion.

The interaction of SES and Working Memory (SES*Working Memory) and the interaction of SES and Cognitive Flexibility (SES*Cognitive Flexibility) were each analyzed separately. The first interaction analysis completed was for SES*Working Memory for the end of first, second, third, and fourth grade, and the results are reported in Table 6. With the addition of SES*Working Memory, the model was significant for the end of first grade reading, $F(5, 3120) = 345.1134$, $p < .001$. The model explained 35.6%

of the variance of reading achievement, which is only 0.10 more variance compared to the original model. Specifically, the interaction term SES*Working Memory was significant, $b = -.001$, $p = .019$. Upon further analysis, it was found that the impact of working memory was higher for those that were 1 standard deviation below the mean SES. The impact of working memory lessened as SES increased. Results for the conditional impact of working memory at one standard deviation below, the average, and one standard deviation above on SES are reported in Table 7.

Table 6

*Model Summary of Multiple Linear Regression with Interaction Effects for SES*Working Memory for End of First, Second, Third, and Fourth Grade of Reading Achievement*

	T4		T6		T7		T8	
Variable	*b*	*p*	*b*	*p*	*b*	*p*	*b*	*p*
Gender	0.106	<0.001	0.122	<0.001	0.139	<0.001	0.081	<0.001
SES	0.217	<0.001	0.204	<0.001	0.207	<0.001	0.201	<0.001
Working Memory	0.010	<0.001	0.008	<0.001	0.008	<0.001	0.007	<0.001
Cognitive Flexibility	0.024	<0.001	0.021	<0.001	0.023	<0.001	0.016	<0.001
SES*WM	-0.001	0.019	-0.001	0.18	-0.001	<0.001	-0.001	<0.001

Note: T4 is the spring of first grade, T6 is spring of second grade, T7 is spring of third grade, and T8 is spring of fourth grade. $N = 3126$

The model was also significant for end of second grade, $F(5, 3120) = 331.2703$, $p < .001$. The model explained 34.7% of the variance, but SES*Working Memory was not a significant predictor, $b = -.001$, $p = .18$. The model was significant for the end of third grade reading, $F(5, 3120) = 341.4210$, $p < .001$. The third grade model explained 35.6%

of variance, and there was a significant interaction, *b* = -.001, *p* = .01. The same interaction effect that was found for first grade reading was also found here. Finally, the fourth grade model was also significant, *F*(5, 3120) = 286.2221, *p* < .001. The model explained 31.5% of the variance, and an interaction effect was found. It was the same effect as the previous two interactions when rounded to the thousandths place, *b* = -.001, *p* = .04.

Table 7

Model Summary of Interaction Effects between SES and Working Memory

	T4		T7		T8	
SES Level	*b*	*p*	*b*	*p*	*b*	*p*
1 SD below	0.011	<0.001	0.009	<0.001	0.008	<0.001
Mean	0.001	<0.001	0.008	<0.001	0.007	<0.001
1 SD above	0.009	<0.001	0.007	<0.001	0.007	<0.001

Note: T4 is the spring of first grade, T7 is spring of third grade, and T8 is spring of fourth grade, *N* = 3126; interaction effects for T6 is not reported because it was not significant

Previously research has shown that both SES and CF impacts reading, so an interaction term was created to investigate the interaction of SES and CF on reading achievement. Results are shown in Table 8. No significant interactions were found in any of the models. The model was significant for first grade reading, *F*(5, 3120) = 343.4068, *p* < .001. The model explained 35.5% variance. The model was also significant for second grade reading, *F*(5, 3120) = 330.7244, *p* < .001, and the model explained 34.6% of the variance. The third grade model significantly explained 35.6% of the variance, *F*(5, 3120) = 339.4178, *p* < .001. Finally, fourth grade reading model significantly explained 31.4% of the variance, but no interaction effect was found, *F*(5, 3120) = 284.9378, *p* <.001.

Table 8

*Model Summary of Multiple Linear Regression and Interaction Effects for SES*Cognitive Flexibility for End of First, Second, Third, and Fourth Grade*

	T4		T6		T7		T8	
Variable	*b*	*p*	*b*	*p*	*b*	*p*	*b*	*p*
Gender	0.106	<0.001	0.122	<0.001	0.139	<0.001	0.080	<0.001
SES	0.217	<0.001	0.203	<0.001	0.206	<0.001	0.200	<0.001
WM	0.010	<0.001	0.008	<0.001	0.008	<0.001	0.007	<0.001
CF	0.024	<0.001	0.021	<0.001	0.023	<0.001	0.016	<0.001
SES*CF	0.00	0.93	0.00	0.96	-0.030	0.48	0.001	0.70

Note: T4 is the spring of first grade, T6 is spring of second grade, T7 is spring of third grade, and T8 is spring of fourth grade. *N* = 3126

Latent growth model. The data were analyzed using latent growth modeling for the third, fourth, and fifth research questions. Latent growth modeling is a type of structural equation modeling that looks at change over time (Singer & Willett, 2003). The ECLS-K:2011 database meets the four guidelines set forth by Bryne (2011), the variables are continuous, the data collection was completed at the same time for all participants, there are more than three data collection points, and the sample size (*n* = 3126) is large enough to detect person-level effects. The IBM SPSS (version 24) AMOS module was used for the analyses.

Growth of Reading Achievement

The next research question investigated the impact of working memory and cognitive flexibility at kindergarten on the intercept and slope of reading achievement. To begin, trend analysis was completed to investigate the eight time points of reading achievement. The analysis showed a significant linear relationship, $F(1,3125) = 77514.641$, $p < .001$, as well as a quadratic relationship, $F(1,3125) = 5592.2997$, $p < .001$. This relationship is shown in Figure 1. In all analyses, we used linear modeling as the linear relationship was dominate over the quadratic one. The fact that the quadratic term is significant is likely due to the large sample size.

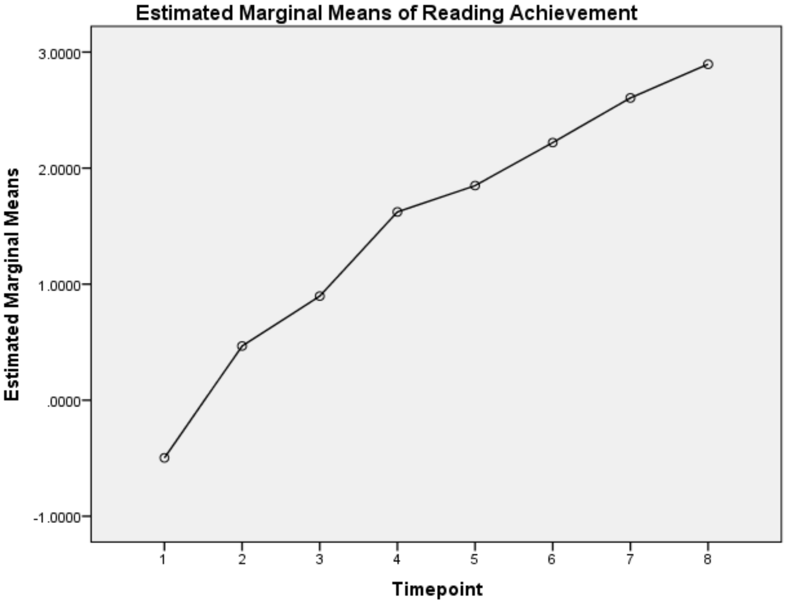

Figure 1. Trend Analysis of Reading Achievement Scores Over Time.

An unconditional growth model was created to investigate the model fit of how reading achievement grew over time. Multiple measures of fit are analyzed when completing growth modeling (Byrne, 2011). Random measurement errors are represented by the letter E and were correlated in the models (as represented by the non-directional lines among the E's). The analyses revealed that the data did not fit the model (χ^2=6113.405, *df* =12, χ^2/df = 409.450, CFI = .801, RMSEA = .403. SRMR = .161), indicating that the observed data did not fit the model well. The graphical representation of the unconditional model is located in Figure 2.

Due to the lack of fit for the data, no further analyses were done regarding growth of reading achievement. A correlation matrix was created to determine if the variables were too highly correlated. As Table 9 shows, the range of correlations were from .57 – .90. It is possible that the highly correlated variables are causing the model to not fit the data.

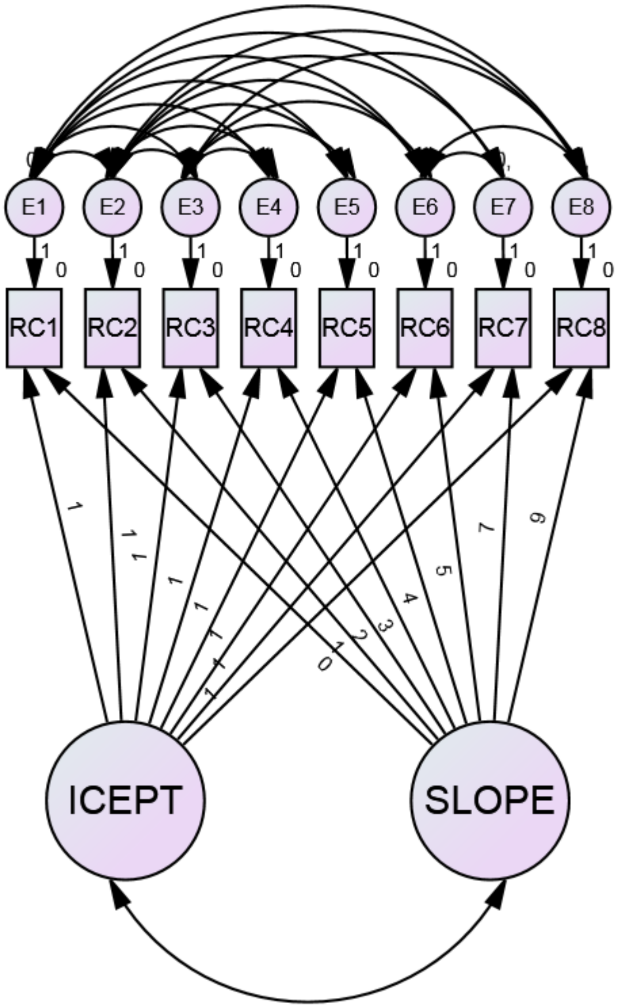

Figure 2. Unconditional Growth Model of Reading Achievement

Table 9

Correlations Between Reading Achievement Data Points (N = 3126*)*

Time Point	1	2	3	4	5	6	7
1							
2	0.78						
3	0.76	0.85					
4	0.69	0.80	0.86				
5	0.65	0.75	0.82	0.90			
6	0.63	0.72	0.78	0.86	0.89		
7	0.59	0.66	0.70	0.78	0.80	0.84	
8	0.57	0.66	0.71	0.79	0.81	0.84	0.83

Note. All correlations are significant at the .01 level.

Growth of Working Memory

The next research question investigated the growth of working memory over time. A trend analysis was completed to understand the growth of working memory. The results showed a significant linear relationship, $F(1,3125) = 16035.839$, $p < .001$, as well as a quadratic relationship, $F(1,3125) = 428.752$, $p < .001$. In all analyses, we used linear modeling as the linear relationship was dominate over the quadratic one. The fact that the quadratic term is significant is likely due to the large sample size.

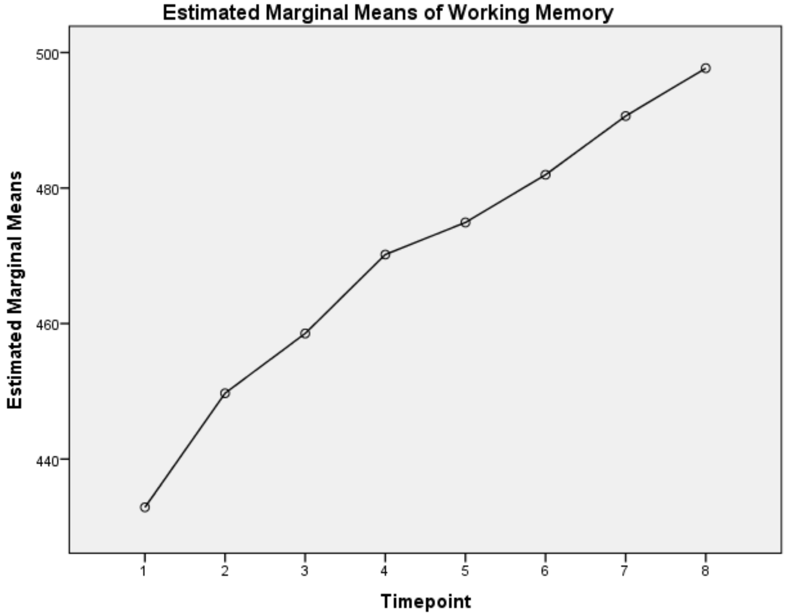

Figure 3. Trend Analysis of Working Memory Over Time

An unconditional model was created to investigate the growth of working memory. A graphical representation of the model is reported in Figure 4. The results showed the unconditional model does not have an acceptable fit (χ^2=1532.728, *df* =18, χ^2/*df* = 85.152, CFI = .859, RMSEA = .164, SRMR = .040). Due to the lack of fit for the model, no further analyses were completed for this question. Correlations are reported in Table 10.

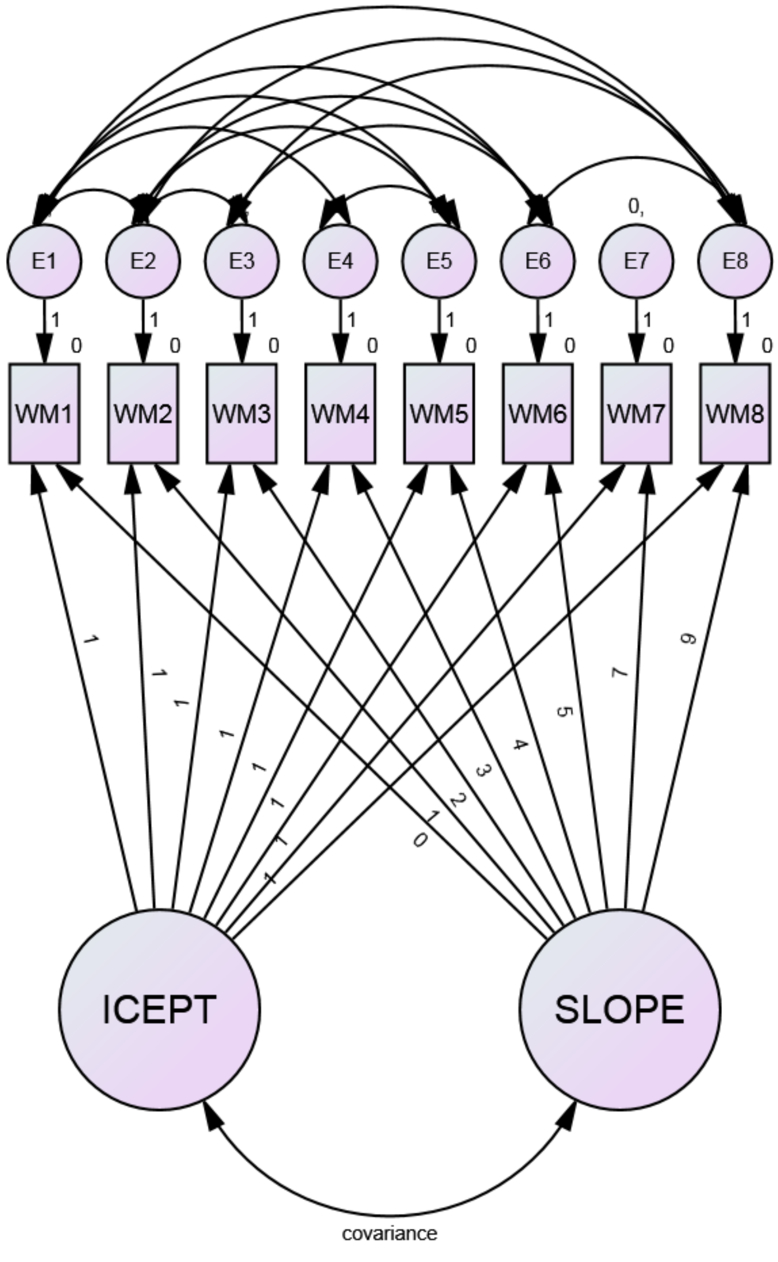

Figure 4. Unconditional Model of Working Memory Growth

Table 10

Correlations Between Working Memory Data Points

Time Point	1	2	3	4	5	6	7
1							
2	0.57						
3	0.49	0.56					
4	0.43	0.49	0.51				
5	0.40	0.45	0.51	0.55			
6	0.38	0.42	0.47	0.52	0.56		
7	0.40	0.40	0.45	0.47	0.52	0.60	
8	0.40	0.38	0.41	0.45	0.50	0.56	0.62

Growth of Cognitive Flexibility

The next question investigated how cognitive flexibility grew over time and the impact of SES on the slope and the intercept of that growth. ECLS-K:2011 changed how cognitive flexibility was measured after the fourth time point at the end of the first grade. The first four data points were measured using physical cards while the last four time points were measured using a computer. ECLS recommended that the first four data points not be compared to the last four time points. Because of that, only the first four data points were used for this analysis. A separate analysis was conducted for the last four data points. Before the growth modeling, a trend analysis was completed. That can be found in Figure 5. Results showed a significant linear relationship, $F(1,3125) = 1096.662$, $p < .001$. A quadratic relationship was also found, $F(1,3125) = 90.494$, $p < .001$, which is likely due to sample size.

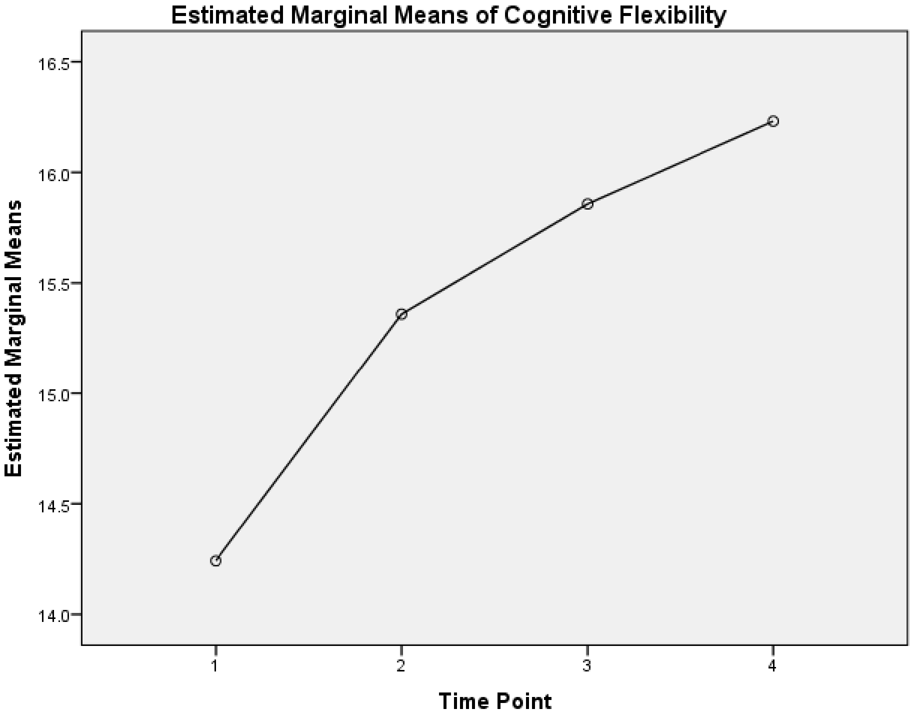

Figure 5. Trend Analysis of the First Four Cognitive Flexibility Data Points

An unconditional model was created for cognitive flexibility for the first four time points. The graphic of the model is shown in Figure 6. Modification indices indicated that the best fitting model included a correlation between the error terms for time 2 with time 1 and time 6. The results showed the conditional model had an acceptable fit based on multiple measures (χ^2=90.330, *df* =3, χ^2/df = 30.11, CFI = .916, RMSEA = .097. SRMR = .005). Results showed that there was a negative correlation between the intercept and slope in the model (-.70, *p* = .005). Students with greater cognitive flexibility at time one had a lower growth over time than those with lower cognitive flexibility.

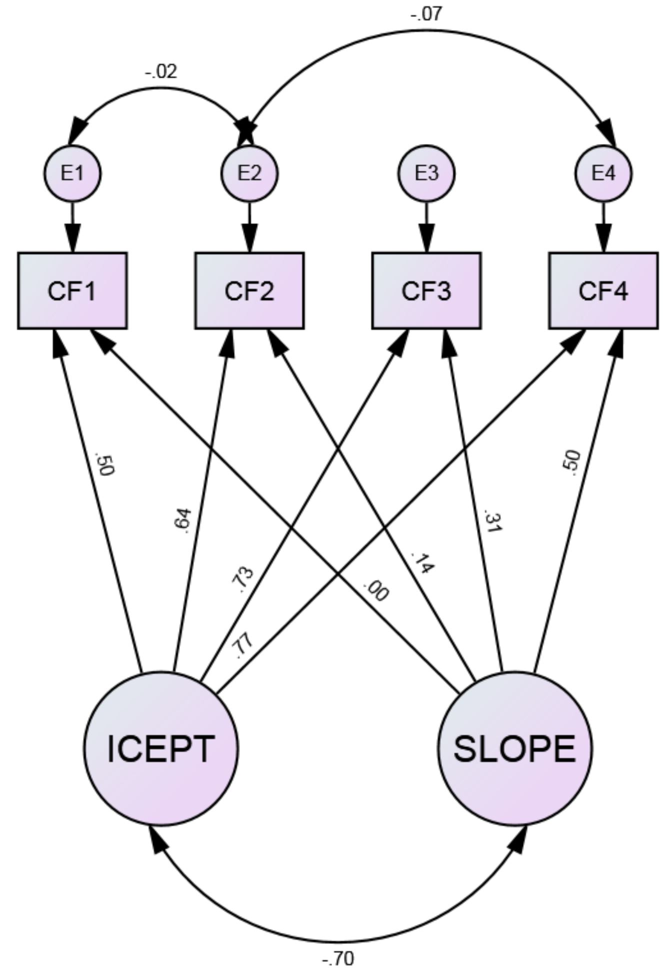

Figure 6. Unconditional Growth Model of the First Four Cognitive Flexibility Time Points

Figure 7 shows the conditional model that was created to investigate SES's impact on the slope and intercept of students' cognitive flexibility for the first four time points. The results showed the conditional model had an acceptable fit (χ^2=93.192, *df* =5, χ^2/df = 18.638 CFI = .932, RMSEA = .075. SRMR = .008). The analysis found that SES was a significant predictor for both the intercept (β =.37, $p < .001$) and slope (β = -.24, $p < .001$). Additionally, there's a negative correlation between the slope and intercept (-.684, $p = .005$) Students with higher SES started kindergarten with higher cognitive flexibility than those with lower SES**.** Additionally, students who entered with a lower SES grew at a faster pace on Cognitive Flexibility than those who from a higher SES

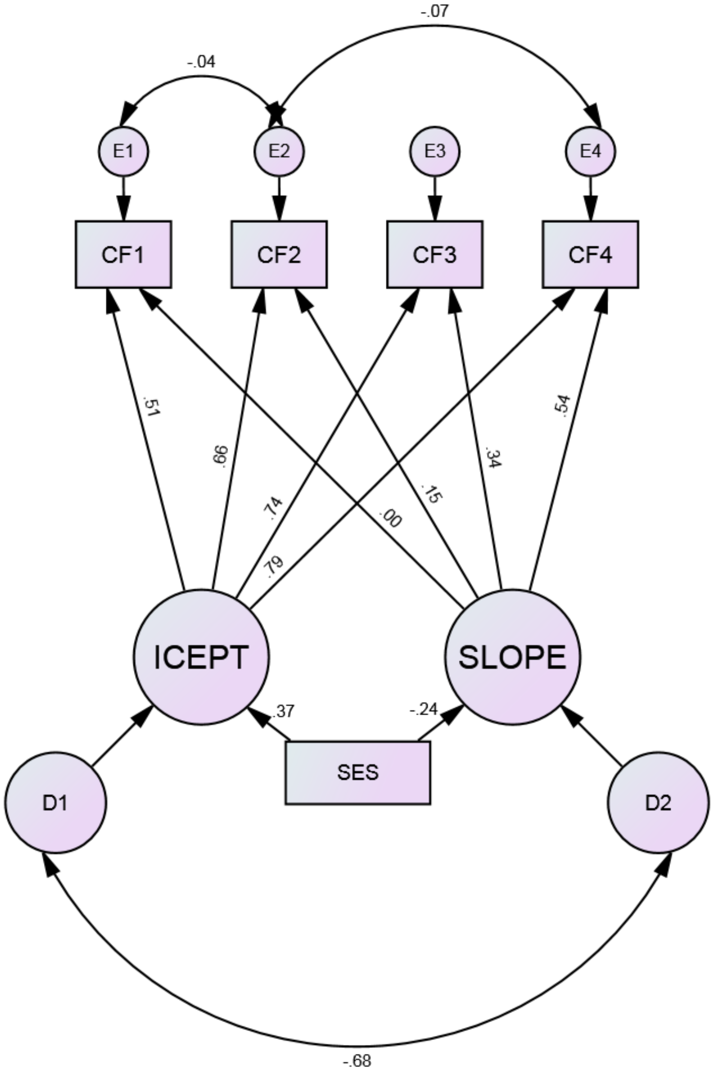

Figure 7. Conditional Growth Model of Impact of SES on the First Four Cognitive Flexibility Time Points

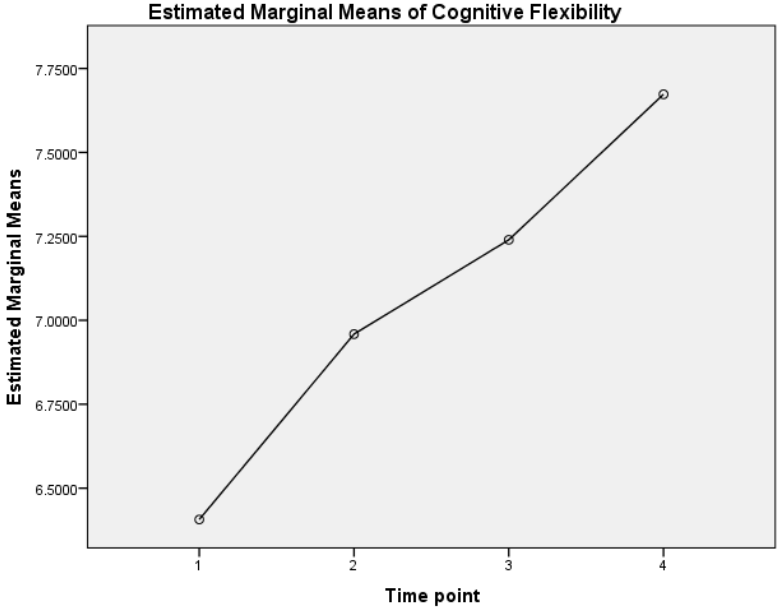

Figure 8. Trend Analysis for the Last Four Cognitive Flexibility Time Points

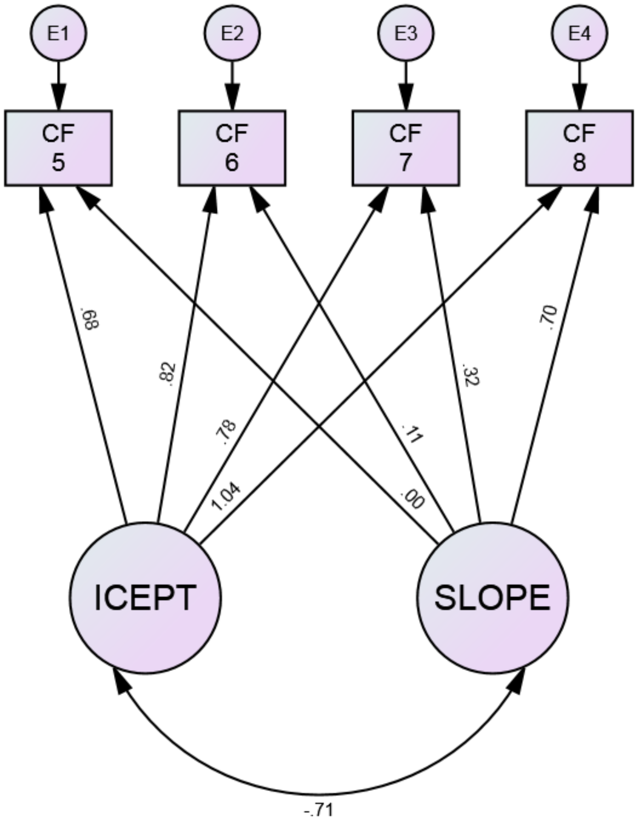

Figure 9. Unconditional Growth Model of the Last Four Cognitive Flexibility Time Points

An additional analysis was completed for the last four time points in the data. A trend analysis, reported in Figure 8, was completed and a significant linear relationship was found, $F(1, 3125) = 2758.219$, $p < .001$, as well as a quadratic relationship, $F(1,3125) = 11.005$, $p < .001$. The unconditional model is seen in Figure 9. The results show a mixture of acceptable and poor fits (χ^2=233.184, *df* =5, χ^2/df = 46.637, CFI = .917, RMSEA = .121 SRMR = .011). While RMSEA shows a poor fit, CFI found an acceptable fit while SRMR found a good fit. Results showed that there was a negative correlation between the intercept and slope in the unconditional model (-.713, *p* = .<.001). Students with greater cognitive flexibility at time five had a lower growth over time than those with lower cognitive flexibility.

A conditional model was created to determine SES's impact on the growth of cognitive flexibility over the final four time points. The results show the conditional model had an acceptable fit based on NFI and CFI statistics and a good fit based on SRMR (χ^2=238.184, *df* =7, χ^2/df = 34.026, CFI = .921, RMSEA = .103, SRMR = .011). Results showed that SES impacted the slope (β = -.199, p < .001) and intercept (β = .257, p < .001). Additionally, there was a negative relationship between the slope and intercept (-.697, *p* < .001). Like the previous analysis, students with higher SES started second grade with higher cognitive flexibility than those with lower SES. As found previously for the first four time points, students entering with lower SES grew at a faster rate compared to those with higher SES on cognitive flexibility. Figure 10 shows the model.

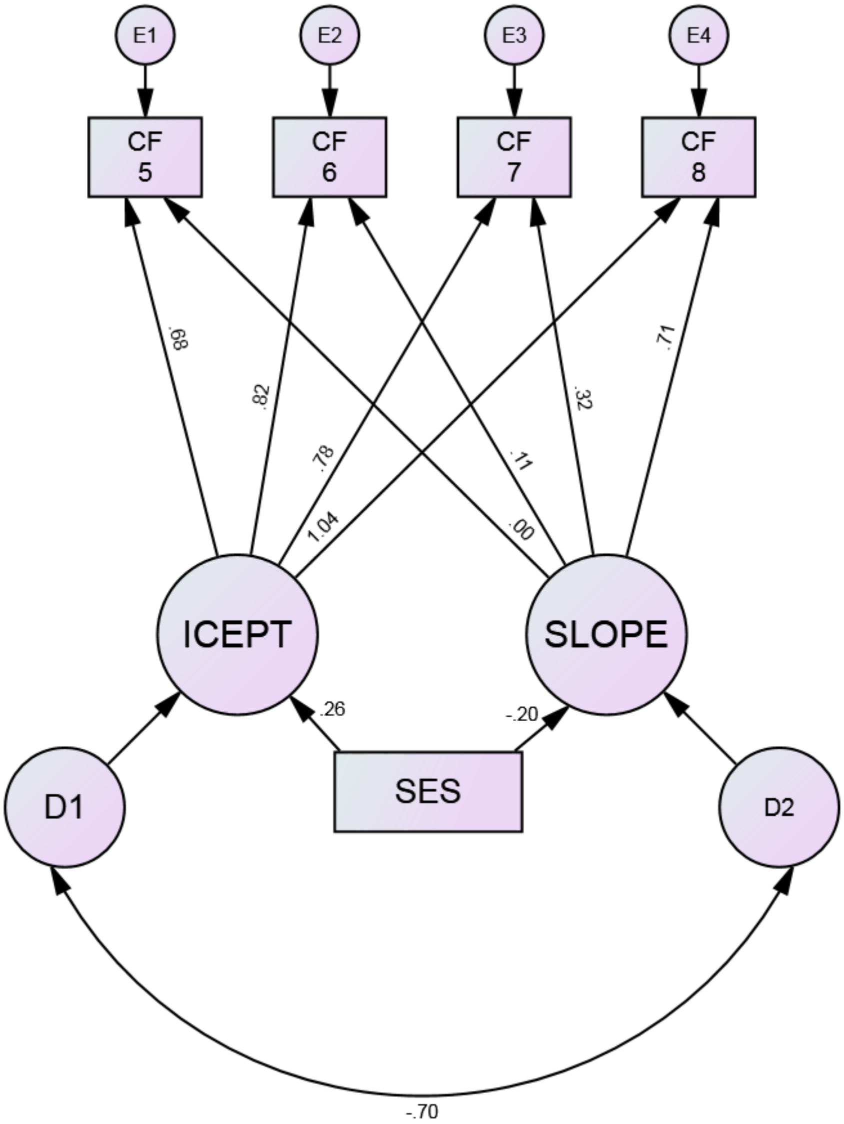

Figure 10. Conditional Growth Model of Impact of SES on the Last Four Cognitive Flexibility Time Points

CHAPTER V

DISCUSSION

Overview

The present study sought to understand the relationships between cognitive flexibility, working memory, SES, and reading achievement through longitudinal research. The present study used data from ECLS:K:2011, which included students from kindergarten until fourth grade. The database provided data on reading achievement, SES, working memory, and cognitive flexibility. This study evaluated how working memory and cognitive flexibility at kindergarten predicted reading achievement at the end of first, second, third, and fourth grade. The impact of SES and gender on reading achievement was also investigated as a predictor.

The change over time of reading achievement, working memory, and cognitive flexibility was also investigated. This investigation included determining how SES, working memory, and cognitive flexibility impacted the slope and intercept of reading achievement. Finally, SES was also examined to understand its impacts on the growth of working memory and cognitive flexibility over time.

The Impact of Working Memory and Cognitive Flexibility as Predictors of Reading Achievement

A multiple linear regression was completed to understand how cognitive flexibility and working memory impacted reading above and beyond SES and gender. Cognitive flexibility and working memory were significant predictors for all time points.

Cognitive flexibility explained between 2.7% – 3.9% of variance from end of the first to end of fourth grade. Additionally, working memory explained between 10.4% - 13.6% of variance. The amount of variance that cognitive and flexibility and working memory explained were, in the most part, reduced from the end of first grade until the end of fourth grade. Cognitive flexibility explained 3.9% at the end of first grade, 3.7% at the end of second grade, 4.1% at the end of third grade, and 2.7% at the end of fourth. Other than third grade, cognitive flexibility's variance reduced from end of first grade to end of fourth grade. Working memory had similar effects. Working memory explained 13.6% variance at the end of first grade, 11.7% at the end of second grade, 11.7% at the end of third grade, and 10.4% at the end of fourth grade. As students get older, cognitive flexibility and working memory's variance is reduced.

Similar results were found for the full model. With the addition of the gender and SES, the full model explained between 31.3% - 35.5% of variance between the end of first and the end of fourth grade reading achievement. The present study found that the explanation of variance in the model was reduced from the end of the first grade until the end of fourth grade. At the end of the first grade, the model explained 35.5% of the variance, and by the end of the fourth, the full model explained 31.5% of the variance. As the student gets older, there may be other variables that explain more variance than executive function. More longitudinal research should be conducted to understand how executive function and SES at kindergarten impact reading throughout middle and high school.

The present study extends the research showing that cognitive flexibility and working memory are significant predictors of reading comprehension longitudinally (Cole et al., 2014; Guajardo & Cartwright, 2016; Latzman et al., 2010; Morgan et al., 2016; Roberts et al., 2015). These findings are similar to Guajardo and Cartwright who found that working memory and cognitive flexibility between the ages of 3 and 5 were both significant predictors in reading comprehension three years later. They also found that working memory was more impactful to later reading comprehension than cognitive flexibility, which was found in this study. The present study also extended the work of Morgan et al. (2016). Morgan and colleagues used the same ECLS-K:2011 database to show that kindergarten cognitive flexibility was predictive of end of first grade reading. They found that students with working memory and cognitive flexibility deficits were at increased risk of having reading deficits at the end of first grade. Specifically they found that while both were significant, working memory was more impactful than cognitive flexibility. The present study confirmed that cognitive flexibility was predictive of end of the first grade reading, but the present study extended Morgan et al.'s finding to show that cognitive flexibility was predictive of end of second, third, and fourth grade reading achievement. The implications are that cognitive skills of kindergarteners are still impacting reading ability later in elementary school.

Previous research has also shown that cognitive flexibility explains variance for a wide variety of ages. Cantin and colleagues (2016) found that cognitive flexibility was a significant predictor for reading comprehension of 7 to 10 year olds, while Nouwens et al. (2016) found the same effect for 5th graders. Similar results have be found up to age 16 (Latzman et al., 2010). Other studies have only looked at cognitive flexibility and reading at the one time point (Cantin et al., 2016; Nouwens et al., 2016). The present study extended this research towards longitudinal data to understand the impact of cognitive flexibility over multiple grades. Throughout first to fourth grade, cognitive flexibility was a significant predictor. Working memory was also a significant predictor at all time points. This matches well with multiple studies (Alloway & Alloway, 2010; Cain et al., 2004; Daneman & Carpenter, 1980), but differs from others that did not find cognitive flexibility a significant predictor of reading (Monette et al., 2011; Roberts et al. 2015).

This study is in sharp contrast to findings that found cognitive flexibility was not a predictor of reading (Monette et al., 2011; Roberts et al. 2015). Monette et al. (2011) did not find kindergarten cognitive flexibility as a predictor of first grade reading while finding other executive function skills as significant predictors of first grade reading (e.g., inhibition and working memory). While Roberts et al. (2015) found that there was a significant correlation between cognitive flexibility and reading comprehension (.31) among third grade students, when cognitive flexibility was added into a regression model along with word reading, listening comprehension, prosody, and vocabulary, cognitive flexibility was not found to be a significant predictor of reading comprehension. Cognitive flexibility was the only executive function skill measured in the study. The study did not add working memory or other executive function skills into the model. The present study was unable to add specific reading skills into the regression model.

The Impact of Interaction Effects on Reading Achievement

The present study also examined an interaction between socioeconomic status and working memory, as well as socioeconomic status and cognitive flexibility. There was a significant interaction effect between SES and working memory, in which it was found that working memory had more impact on reading achievement as students' SES decreased. This finding showed that students who have lower SES may need to rely more on working memory to understand text. Additionally, the addition of the SES*working memory interaction term only added a small amount of explained variance, and these effects should be treated with caution because of the small increase of variance is likely due to the large sample size. No interaction effect was found between SES and cognitive flexibility. While the present study had a very small effect for SES and working memory, future studies should investigate how much variance working memory explains in reading achievement between low SES students versus students who are not. The investigation should determine if executive function plays more of a role in literacy for low SES students in poverty than their peers.

Investigating Growth of Reading, Working Memory, and Cognitive Flexibility

Growth modeling was used to evaluate the growth of reading achievement, working memory, and cognitive flexibility over time. The first growth model sought to evaluate how SES, working memory, and cognitive flexibility impacted the intercept and slope of reading achievement. The investigation of reading achievement growth found the trends to be linear. Before SES, working memory, and cognitive flexibility could be investigate, a basic growth model of reading was completed. The basic, unconditional model of reading was not a good fit, and the model was unable to determine the impact of those predictors on reading achievement.

Growth modeling was also used to evaluate the growth of working memory over time. Growth modeling was completed to understand how working memory grew throughout elementary school, as well as if SES impacted the intercept and growth. The impact of SES on the growth of working memory was not able to be completed because the model did not fit. Like the previous growth model, the unconditional model did not fit the data. The lack of model fit for these measures are different than previous studies who have measured similar variables over time. Grimm (2008) was able to successfully model reading scores from third to eight grade to determine the relationship between math and reading achievement over time. Grimm successfully modeling math and reading achievement from third until eight grade. The present study was not able to successfully model reading achievement. The present study had over 3,000 participants while Grimm’s had over 40,000 participants.

It is unclear why the data in this study did not fit the data as growth could be seen in the descriptive information. One explanation may be a developmental one. For example, the current study investigated growth between kindergarten and fourth grade. There’s a very large difference, developmentally, between a kindergarten reader and a fourth grade reader. On the other hand, as in Grimm’s study, the developmental difference between a third grade reader and an eight grade reader is not as large. By third grade, a reader will have necessary skills for independent reading. That’s not the case for kindergarten students. Another explanation could be the use of standardized scores. Once scores are standardized, it shows you the relative position of the students. Those positions do not change over time, which makes it hard to model growth over time.

Finally, growth modeling was used to evaluate how cognitive flexibility changed over time. Measurement of cognitive flexibility was changed mid-way through data collection. Because of that, two separate analyses were completed. For the first four time points, kindergarten to end of first grade, students who entered into kindergarten with higher cognitive flexibility grew at a slower rate than those who came in with lower cognitive flexibility. Specifically, there was a negative correlation between the intercept and slop in the model. The same results were found for the rest of the time points, which included second grade to fourth grade. There was, again, a negative correlation between the intercept and the slope in last four time points. These findings indicate that students who have deficits in cognitive flexibility grow at a faster rate than those who initially have higher cognitive flexibility. One would expect that students who come into kindergarten behind would have to grow at a faster rate to catch up. Additionally, regression to the mean could play a role. The students who come into the first time point with a low scores will be closer to the mean the next time.

The implications of these findings are that there could be limited reason to intervene since cognitive flexibility grows over school. Specifically, no matter what takes place, it is expected that a student’s cognitive flexibility will grow over time. If that student has lower cognitive flexibility than others, they will grow in their ability at a faster rate than peers with better cognitive flexibility. Random control trials should be conducted to determine if cognitive flexibility intervention at kindergarten produces different results than those who did not receive an intervention. This will allow research to determine if cognitive flexibility is malleable. This will also control for regression to the mean.

The conditional model, with SES included, found that SES impacted the slope and intercept for the first four time points. Higher SES students started kindergarten with better cognitive flexibility. Growth in cognitive flexibility was greater for those from low SES backgrounds compared to those with higher SES. The same effect was found for second through fourth grade. Findings from the present study supports and extends the findings of Sarsour et al. (2011), which found that SES was a significant predictor of cognitive flexibility. Little (2017), who found that students in the top SES quintile scored 1 standard deviation higher than lowest quintile on Numbers Reversed task. While the present study was investigating growth of cognitive flexibility, it showed similar findings to Little, as in there are differences in cognitive flexibility based on the students’ SES. As seen in previous research, the present study found that SES is related to students’ cognitive processes. Specifically, lower SES students' cognitive flexibility grow faster compared to higher SES students.

Limitations of Current Study and Suggestions for Future Research

A limitation of this study is a lack of IQ data from the participants. IQ is correlated to achievement, and research on executive function rarely control for IQ (Jacob & Parkinson, 2015). The lack of IQ data could confound the present study because IQ could have a hidden impact on reading, working memory, and cognitive flexibility. Without access to the IQ data, the present study was not able to investigate that relationship. While Yeniad et al. (2013) found that cognitive flexibility was linked to achievement, IQ was found to be a larger contributor to achievement than cognitive flexibility. On the other hand, Alloway and Alloway (2010) found that working memory was a better predictor to academic achievement than IQ. This study could not confirm that relationship because of lack of IQ data. An additional limitation of this study is the inability to view item level data. The ECLS-K:2011 data does not allow for item level analyses for their reading measure. Specific reading comprehension questions could not be parsed out for this study, which meant an overall reading achievement variable was used. Questions involving word level, vocabulary, and specific types of inferences could not be answered through this data. Future research should continue to investigate reading comprehension and executive function, especially with the link to Kintsch's (1988) model of comprehension. Longitudinal data should collect data on a specific reading skills over time to better understand executive function's contribution to reading. If broken down into specific skills, those individual skills could be analyzed separately to understand the full impact of executive function on reading.

The selection of the subsample is a limitation. Only data without missing data was used in this study. While an analysis reported that the groups were similar in regards to gender and ethnicity, there could be confounding variables between participants who were present for all data collection points and those who were not. The large sample size and small interaction effect must be taken into consideration when understanding the working memory and SES interaction effect. But that small effect, paired with Little's (2017) findings on SES, shows the need for more research to explore the longitudinal impact of SES, executive function, and reading achievement. Future research on executive function should strive to include multiple indicators of SES for participants. The present study had on SES data collection point. It is not known if SES was different before the start of kindergarten or after. Additionally, when investigating executive function intervention, students' SES must be taken into account to determine if interventions are more effective for students with different SES backgrounds. Cartwright's et al. (2017) research on cognitive flexibility's intervention is promising, and the addition of an SES variable could further the literature. Additional work investigating cognitive flexibility growth is needed to replicate the findings of this study. Cognitive flexibility is the least researched facet of executive function (Cartwright et al., 2017; Roberts et al., 2015), and more is needed in the area of cognitive flexibility (Cartwright, et al., 2017; Roberts, Norman).

The measurement of cognitive flexibility was a limitation. When evaluating the growth of cognitive flexibility, the present study was unable to measure consistent growth from kindergarten until fourth grade. The way cognitive flexibility was measured was changed after the fourth time point. Because of that, the first four time points and the last four times points were analyzed separately. This limited the results of the present study because we were unable to consistently track cognitive flexibility from kindergarten until fourth grade. Future studies should strive to keep the same assessment tool throughout. An additional limitation is the use of a domain general cognitive flexibility measure, the Dimensional Change Card Sort (DCCS). An addition of a reading specific cognitive flexibility would allow investigation on if students grow differently in domain or reading specific flexibility. DCCS was specifically created to measure cognitive flexibility starting at age three. Wisconsin Card Sort Task (WCST), another cognitive flexibility measure, could not have been used because kindergarteners are too young. The earliest WCST can be used on a child is at 6.5 years old. The use of WCST would have been inappropriate, and that should be noted for future research.

Conclusion

The present study found that cognitive flexibility, working memory, and SES at kindergarten are all predictors of reading achievement at the end of first, second, third, and fourth grade. The study also found that cognitive flexibility and working memory were significant predictors above and beyond SES and gender. Specifically, this study found that working memory was more impactful to later reading than cognitive flexibility. As time went on, the amount of variance of working memory and cognitive reduced. The next step should be investigating cognitive flexibility intervention studies. Could improving cognitive flexibility increase reading comprehension? Finally, as working memory and cognitive flexibility's variance reduces, are there other variances that are increasing?

The study also found that SES impacts the growth of cognitive flexibility over time, specifically, it shows that as a student's SES decreases, so does their growth of SES over time. The present study sets the groundwork for researchers to continue to investigate how SES impacts cognitive flexibility over time. Additionally, when planning cognitive flexibility interventions, researchers should investigate if investigations are more impactful for students with lower SES.

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