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THE ROLE OF EXECUTIVE FUNCTION IN SUPPORTING READING FLUENCY IN STUDENTS WITH DYSLEXIA: A LATENT GROWTH CURVE ANALYSIS

by

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Abstract

The purpose of this study was to examine the role of executive function (EF) skills (i.e., working memory, cognitive flexibility, and inhibition) in supporting the development of reading fluency in elementary school students with dyslexia. Participants were 47 students (i.e., second to sixth grade) attending a private school in the Mid-South region of the United States that provides an intensive day-treatment program for students diagnosed with dyslexia. Latent Growth Curve Modeling (LGCM) was used to explore the concurrent and predictive relation between EF and oral reading fluency across a school year. Overall, results from the study indicated that executive function skills (i.e., working memory, cognitive flexibility, and inhibition) did not significantly predict growth in reading fluency scores across the school year, and only inhibition emerged as a significant predictor for baseline reading fluency scores in the fall. More surprisingly, initial reading scores at the beginning of the school year did not predict the amount of growth across the fall or spring semesters. Given the potential impact of methodological limitations (i.e., sample size, collapsing data across grades, and not accounting for potential covariates) on these results, conclusions from this study should be drawn with caution. However, this study illuminates the need for additional research on the complex relation between executive function and reading fluency.

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The Role of Executive Function in Supporting Reading Fluency in Students with Dyslexia: A Latent Growth Curve Analysis

Reading skills are vital to both educational and vocational success. Despite its importance, a large portion of students struggles to develop proficient reading skills. Of the students identified as having a specific learning disability in reading, 70-80% have dyslexia (Al-Lamki, 2012). Dyslexia is a neurological condition that is characterized by primary deficits in accurate and fluent word recognition and phonological processing, with secondary deficits in vocabulary, reading fluency, and reading comprehension (Lyon, Shaywitz, & Shaywitz, 2003; International Dyslexia Association, 2002). Research suggests that intense intervention is successful in remediating many of these deficits, especially those in decoding, spelling, word reading, and reading comprehension (Ehri, Nunes, Stahl, & Willows, 2001; Goodwin & Ahn, 2010). However, problems with oral reading fluency often persist, particularly at the level of connected text (Denton et al., 2013; Lefly & Pennington, 1991; Christodoulou et al., 2014; Shaywitz, 2003; Lyon & Moats, 1997; Meyer et al., 1999; Torgeson et al., 2001). Reading fluency is an individual's ability to read with appropriate prosody, accuracy, and automaticity (Kuhn, Schawenflugel, & Meisinger, 2010). Some research even supports the existence of a reading fluency disability subtype (Meisinger, Bloom, & Hynd, 2010). That is, some students with dyslexia demonstrate average word reading/decoding skills but experience specific deficits in reading fluency (Meisinger et al., 2010).

It has been well established that individuals with dyslexia have core deficits in phonological processing, specifically phonological awareness (Melby-Lervag, Lyster, & Hulme, 2012). Phonological awareness is the ability to manipulate the sound components of words (Steacy, Kirby, Parrila, & Compton, 2014). Others have noted rapid automatized naming (RAN) speed deficits in individuals with dyslexia (Wolf, Bowers, & Biddle, 2000), with some individuals having deficits in both phonological processing and naming speed. Naming speed can be described as an individual's ability to name familiar stimuli (e.g., digits, letters, colors, and objects) rapidly (Steacy et al., 2014). Research has supported the relationship between poor reading abilities and deficits in both phonological awareness (Melby-Lervag et al., 2012) and rapid naming (Wolf et al., 2000; Lervag, & Hulme, 2009; Torppa, Georgiou, Salmi, Eklund, & Lyytinen, 2012). Furthermore, deficits in both phonological awareness and naming speed have predicted future problems with reading, with deficits in both areas being a stronger predictor of reading problems (Wolf & Bowers, 1999; Parrila, Kirby, & McQuarrie, 2004; Steacy et al., 2014).

In addition to key deficits (e.g., phonological awareness and rapid naming speed), students diagnosed with dyslexia may experience difficulty with areas of executive function (EF) compared to typically developing students (Cutting, Materek, Cole, Levine, & Mahone, 2009; Gathercole, Alloway, Willis, & Adams, 2006; Reiter, Tucha, & Lange, 2005). Given the association between EF skills and several core areas of academic achievement (St. Clair-Thompson & Gathercole, 2006), it is essential to understand the role of EF for struggling readers. Researchers have explored the relation between EF and both basic word reading (i.e., word recognition and decoding) and reading comprehension in clinical and typically developing populations (Cantin et al., 2016; Best, Miller, Naglieri, 2011; Sesma, Mahone, Levine, Eason, & Cutting, 2009; Miyake et al., 2012; Cutting et al., 2009; Locascio, Mahone, Eason, & Cutting, 2010; Cain, Oakhill, & Bryant, 2004). The role of EF in supporting reading comprehension has been well established. However, studies examining the impact of EF on basic word reading has yielded mixed results, with some finding a relation (Messer, Henry, & Nash, 2016; Locascio et al., 2010) and others not supporting a relation between the two constructs (Sesma et al., 2009). However, a substantial gap in the literature exists regarding the relation between EF and reading fluency (Cartwright et al., 2016; Cutting et al., 2009). Since dysfluency at the text level is widely viewed as a marker of dyslexia (Christodoulou et al., 2014), it is important to consider the relation between EF and the construct of text reading fluency for this population.

Reading Fluency

Reading fluency refers to an individual's ability to read accurately, automatically, and with appropriate expression (i.e., prosody) (Kuhn, Schawenflugel, & Meisinger, 2010). Although the term reading fluency is used in the literature to describe reading at both the word and text level, research suggests that word reading fluency and text reading fluency represent distinct skills (Cutting et al., 2009). For the sake of parsimony, oral reading fluency assessed at the level of connected text will be referred to as reading fluency throughout this paper. Developing proficiency in reading fluency is vital for students' academic success. A primary goal during second and third grade is to become a fluent reader. However, by fourth grade the pedagogical focus shifts from learning how to read to reading to gain new information (Chall, 1996). Dysfluent students may avoid reading, experience frustration during reading activities, and may not develop their reading skills at the same rate as their peers producing a cumulative disadvantage phenomenon (Stanovich, 1986; Leinonen et al., 2001). Students who do not develop sufficient fluent reading skills are at-risk for falling behind academically, as they are not able to access the content area information provided in curricular texts. In sum, reading fluency has been recognized as an essential aspect of dyslexia (Cutting et al., 2009; Fuchs, Fuchs, Hosp, & Jenkins, 2001; Meisinger et al., 2010).

Reading fluency is often described as the “bridge” between decoding words and reading comprehension (Pikulski & Chard, 2005). Automaticity theory (LaBerge & Samuels, 1974) has been widely used to illuminate the relation between reading fluency and reading comprehension (Levy & Rasinski, 2010). Automatic processes require little to no cognitive or attentional resources, occur quickly, accurately, and without intent or conscious awareness of the individual (Logan, 1985). This serial processing stage model highlights the developmental nature of reading, first describing lower level tasks (i.e., basic word reading), then intermediate tasks (i.e., text reading fluency), and finally more complex tasks (i.e., reading comprehension). In conclusion, automaticity theory posits that for a reader to gather meaning from text, several processes of information must occur.

LaBerge and Samuels (1974) suggest that one’s attentional capacity is both limited and selective. The more attention required by a particular task, the fewer resources are available for other processes. For example, beginning readers initially decode unknown words in a slow, laborious manner. As students become accurate and then automatic word readers, they are eventually able to read words as quickly as they can read a single letter (or unit). As a task becomes automatic, the demands on attention decrease allowing the remaining resources to be used for other processes such as reading comprehension. LaBerge & Samuels (1974) further highlighted the sequential developmental nature of these reading skills, emphasizing that lower-level skills must first become automatic to support higher-level skills. Supporting this notion, meta-analytic findings suggest that students who mastered lower-level tasks (e.g., phonics) were better able to perform higher level-tasks (e.g., word reading, spelling, and text comprehension) (Ehri, Nunes, Stahl, & Willows, 2001). Research has also demonstrated that higher levels of processing need not await the development of lower levels, suggesting that the strict bottom-up approach doesn't adequately represent reading (Stanovich, 1980). Others have proposed a more interactive model of reading compared to bottom-up (or top-down) serial-order models (Stanovich, 1980). The interactive-compensatory model assumes that deficits in skills will result in a heavier reliance on other processes, regardless of the order in which the skill falls within the hierarchy. For instance, a context facilitation effect has been found for word recognition such that words are read faster and more accurately in context than when reading in isolation (i.e., word lists) (Stanovich, 1980).

It is important to understand that distinct skills contribute to a task becoming automatic at differing levels (i.e., lower-level vs. higher-level). Consequently, the literature has extensively examined the underlying cognitive mechanisms, namely executive function, that contribute to an individual's ability to decode words accurately (i.e., lower-level skill) (Messer, Henry, & Nash, 2016; Locasico, Mahone, Eason, & Cutting, 2010) and reading comprehension (higher-level skill) (Cutting, Materek, Cole, Levine, & Mahone, 2009; Cartwright, Coppage, Lane, Singleton, 2016). However, there appears to be a shortage of research regarding the role of executive function in supporting reading fluency, despite its important role as the bridge between basic word reading and reading comprehension.

Executive Function

Executive Function (EF) is a multifaceted construct that refers to a broad set of supervisory cognitive process responsible for higher-order cognitive functioning such as sequencing, working memory, flexibility, initiation, inhibition, planning, coordinating, and shifting attention (Anderson, 2002). The construct of EF is best characterized as unity and diversity (Friedman & Miyake, 2017). That is, there appears to be a shared commonality between EF skills, yet they are distinct. For instance, inhibitory control is involved in cognitive flexibility because one must inhibit their current activity to switch to another one efficiently. Given the multidimensional nature of EF and diversity across definitions, a universal model of the construct has not yet been adopted. However, consensus exists supporting the EF model presented by Miyake et al. (2000) comprised of working memory, inhibition, and cognitive flexibility as the core EF skills recognized and assessed in the neuropsychological community (Miyake et al., 2000; Alvarez & Emory, 2006; Best & Miller, 2010; Peterson & Welsh, 2014). Therefore, these three distinct but related skills will be the EF skills for the current study.

EF skills are housed in the frontal lobes, specifically the prefrontal cortex; however, multiple pathways and areas of the brain are involved in these skills (Luria, 1973; Semrud-Clikeman & Ellison, 2009). Research has supported that the prefrontal cortex is under considerable maturation at the neuroanatomical and cognitive level throughout childhood and into early adulthood (Tsujimoto, 2008; Best & Miller, 2010; Chase et al., 2008; Xu et al., 2013; Jurado & Rosselli, 2007; Garon, Bryson, & Smith, 2008). Tsujimoto (2008) reviewed the current research examining the nature of these neuroanatomical and cognitive changes in the prefrontal cortex throughout the maturation process. At the neuroanatomical level, growth in the prefrontal cortex is evident by increases in white and grey matter volume, substantial dendrite growth, and a reduction in the density of neurons and synapses. Regarding cognitive development, working memory and inhibition emerge around four years of age and improve substantially throughout childhood and adolescence (Tsujimoto, 2008). Cognitive flexibility begins developing around seven years of age and is considered mature by 12 years of age (Anderson, 2010). Thus, as students enter school, both EF and reading skills are under a state of development though maturation is reached at different ages.

Working memory is an individual's ability to hold, manipulate, recall, and associate information with new incoming information (Baddeley,1992; Barkley, 1997). In clinical and research settings working memory is often measured using a Digit Span Backward Task, where individuals are read a series of numbers and asked to repeat the numbers in reverse order (Walda, Weerndenburg, Wijants, & Bosman, 2014; Booth, Boyle, & Kelly, 2010). Related to reading, working memory is one of the processes required to blend letters in order to read unknown words fluently. Furthermore, individuals must use their working memory to hold and integrate the information read to answer comprehension questions.

Inhibition can be described as the cognitive control necessary to over-ride or stop mental prepotent processes. In other words, inhibition allows for an individual to make decisions/acts despite possible interfering demands (Macleod, 2007; Friedman & Miyake, 2004; Barkley, 1997). The traditional clinical and research task utilized to measure inhibition is the Stroop Color-Word Test (Booth, Boyle, & Kelly, 2010). Logically, it makes sense that inhibition is a necessary skill for successful decoding, fluent reading, and reading comprehension. That is, individuals must block out stimuli (e.g., prepotent responses due to familiarity) competing for attention to focus on the task at hand. An example of a prepotent response is a child reading adjunct as adjective.

Lastly, cognitive flexibility is defined as one’s ability to switch or shift thinking while completing a task and is often measured via the Trails Making Test-B (TMT-B; Reitan & Wolfson, 2004). In other words, cognitive flexibility allows one to switch strategies, preventing rigid approaches to solving problems (Diamond, 2013). Cognitive flexibility is thought to be important to reading as it allows the readers to direct attentional resources where needed. For example, when an individual encounters an unknown word, their attention is shifted to use of a decoding strategy, and after the word is identified attention is refocused on the integration of information in the text.

These three EF skills are important to examine when exploring individual reading abilities as they have been found to predict basic word reading (Messer et al., 2016; Locascio et al., 2010) and reading comprehension (Guajardo & Cartwright, 2016; Cutting et al., 2009; Sesma et al., 2009; Cain et al., 2004). EF skills may represent important higher-level cognitive processes that support the development of proficient reading skills. Theoretically, this assumption aligns with both automaticity theory (LaBerge & Samuels, 1974) and the interactive-compensatory model of reading (Stanovich, 1980). Developing proficient foundational skills in these core EF areas should support the development of reading skills (i.e., decoding, reading fluently, and comprehending text). However, the development of cognitive processes and reading skills do not occur in an entirely serial fashion. For instance, individuals may not be able to decode all words while reading connected text automatically, yet they may be able to comprehend much of the text. Similarly, if an individual exhibits a weakness in one EF skill, then he or she may compensate by relying more heavily on other EF skills to carry out tasks. Thus, about reading fluency, it is important to examine the unique contribution of distinct EF skills, as research in this area is limited.

It has long been established that assessments are the gold standard in neuropsychological assessment (Harvey, 2012; Lezak, Howieson, Bigler, & Tranel, 2012; Castellanos, Kronenberger, & Pisoni, 2016). Despite their common use, concerns regarding the validity and generalizability of executive function measures have been noted (Gioia, Isquith, Retzlaff, & Espy, 2002; Castellanos, Kronenberger, & Pisoni, 2016). In particular, performance in a clinical setting at a single time point may not generalize to other areas of life (e.g., school, home, daily living, other cognitive measures, etc.). To address this concern, behavioral rating forms (e.g., self-report, parent-report, and teacher-report) may be to complement clinical assessments in practice and research (Spooner & Pachana, 2006; Gioia, Isquith, Retzlaff, & Espy, 2002). However, the behavioral rating forms to assess EF are not without their problems. These rating forms often produce discrepancies across informants (Steward et al., 2017; De Los Reyes et al., 2011; DeLos Reys & Kazdin, 2002; Grills & Ollendick, 2003; Bein, Detrik, Saunders, & Wojcik, 2015). Parents of students with disabilities may under-report or over-report areas of weaknesses (Koivisto et al., 2015), and teachers tend to under-report internalizing problems compared to parents and self-report of the student (Youngstrom, Loeber, & Stouthamer-Loeber, 2000; Grills & Ollendick, 2002). Furthermore, youth may not be able to accurately report on their disability, with research demonstrating that they often under-report deficits (Steward et al., 2017; Loeber, Green, Lahey, 1990; Loeber, Green, Lahey, & Stouthamer-Loeber, 1991). Lastly, research has supported a lack of congruity between performance on clinical measures and rating forms in clinical populations, likely measuring different parts of EF (Vriezen & Pigott, 2002). Despite some limitations, it is essential to measure EF skills with clinical measures.

Executive Function and Reading Skills

In recent years, the relation between executive function and specific reading skills (i.e., basic word reading/decoding, reading fluency, and reading comprehension) has been studied extensively in clinical populations (e.g., students with a reading disability) (Rose & Rouhani, 2012; Gathercole, Alloway, Willis, & Adams, 2006), in typically developing populations (Cantin et al., 2016; Best et al., 2011; St. Clair-Thompson & Gathercole, 2006), and comparing these two populations (Messer et al., 2016; Cartwright et al., 2016; Cutting et al., 2009; Locascio et al., 2010; Sesma et al., 2009). These studies utilized a myriad of research designs and statistical approaches to accomplish this goal with several patterns emerging regarding which reading skills were measured. Some studies have explored reading achievement as a broad construct, incorporating several reading abilities (e.g., basic word reading/decoding and reading comprehension) (Best et al., 2011; Monette & Marie-Claude Guay, 2011; St. Clair-Thompson & Gathercole, 2006). Other studies have explored an individual reading skill, with most research dedicated to reading comprehension (Cutting et al., 2009; Sesma et al., 2009; Cantin et al., 2016) followed by basic reading/decoding skills (Locasico & Cutting, 2010; Messer, 2016; Gathercole et al., 2006). The literature examining reading fluency as the reading construct of interest is comparatively sparse.

Studies that conceptualized reading as a multi-skill construct (i.e., overall reading achievement) primarily examined typically developing students, and results of these studies suggest a positive relation between various EF tasks and reading achievement. However, the construct EF was conceptualized differently across studies, resulting in different EF skills being measured. For instance, Best et al. (2011) examined the relations between EF (i.e., planning/cognitive flexibility) and the broad reading achievement composite on the Woodcock-Johnson Tests of Achievement-Revised (WJ-R; Woodcock & Johnson, 1989) in a normative sample population of students 5 to 17 years of age. Results revealed that while the strength of the relation varied, cognitive flexibility and planning contributed to the overall reading composite and individual subtests (i.e., Letter-Word Identification, Passage Comprehension, Word Attack, and Reading Vocabulary) across ages. Similarly, Gathercole et al. (2006) sought to explore the association between three EF skills (i.e., working memory, inhibition, and shifting) and an end of the year standardized school test in English (i.e., reading, writing, spelling, and handwriting). Results indicated some EF skills (i.e., working memory and inhibition) accounted for unique variance in standardized test scores; however, shifting was not found to contribute significantly to test scores. Another study examined whether EF skills (inhibition, flexibility, and working memory) in kindergarten could predict reading skills at the end of first grade in 89 typically developing, French-speaking, Canadian students (Monette & Marie-Claude Guy, 2011). Results revealed that none of the EF skills uniquely predicted student's score on a reading composite derived from the Word Reading, Reading Comprehension, and Spelling subtests from the Wechsler Individual Achievement Test-Second Edition (WIAT-II; Wechsler, 2002) at the end of first grade. Other factors including pre-academic knowledge and aggression were found to be significant predictors of reading skill. However, in a mediation analysis, working memory and inhibition had indirect effects via aggression on later reading skills. Furthermore, the relation between flexibility and the reading composite was completely mediated by aggression. These findings are not surprising due to the developmental nature of EF. Given that EF skills were measured in Kindergarten, it is possible that EF was in the initial stages of maturation.

Recent research exploring the relation between basic word reading skills and EF in clinical populations has yielded mixed results. Messer et al. (2016) examined this relation in a sample of 160 (88 typically developing and 72 language impaired) students, ranging from approximately 8 to 12 years of age. Hierarchical regression analysis was used to examine the contributions of EF scores (working memory, fluency, planning, inhibition, switching) to word reading fluency. Results indicated a significant relation between fluent word reading and all EF scores except switching, even after accounting for reaction time and naming speed. Locascio et al. (2010) examined whether 86 students (age 10 to 14) identified with a specific disability in basic word reading (*n* = 44), specific disability in reading comprehension (*n* = 18), and typically developing students (*n* = 24) differed regarding EF skills. Three latent EF factors were examined including planning/spatial, working memory, and response inhibition. Relative to the typically developing group, students with a disability in basic word reading exhibited deficits in working memory and inhibition; however, these deficits were not observed after controlling for phonological processing.

The relation between various EF skills and reading comprehension has also been examined in both typically developing and clinical populations. Locascio et al. (2010) also found that students with a specific learning disability in reading comprehension exhibited deficits in one EF skill as compared to their typically developing peers. Specifically, results revealed a deficit in planning compared to typically developing students, even after controlling for phonological processing. In a similar study, Cutting et al. (2009) investigated the relation between EF skills (i.e., planning, organization, monitoring, and working memory) and reading comprehension in 56 students ages 9 to 14 who were identified as typically developing (*n* = 21), experiencing a disability in basic word reading (*n* =18), or experiencing specific reading comprehension deficits (*n* = 17). Results indicated that students with a specific disability in basic word reading scored lower than typically developing students. However, students with a specific reading comprehension disability presented prominent weaknesses in certain EF skills including planning, organization, and monitoring compared to both typically developing students and students with a specific disability in basic word reading. Sesma et al. (2009) found similar results when examining the contributions of working memory and planning on reading comprehension after controlling for other factors (i.e., attention, decoding, reading fluency, and vocabulary). Sixty students age 9 to 15 participated in that study, of whom 16 were identified with a specific deficit in basic word reading, 10 with a specific deficit in reading comprehension, and 34 were typically developing peers. Both working memory and planning were found to be significantly associated with reading comprehensions scores. After controlling for the factors mentioned above in a multiple hierarchical regression, EF factors accounted for 63% of the variance in reading comprehension scores. Although most studies have examined the concurrent relation of EF and reading, Cain et al. (2004) investigated the longitudinal relation between working memory and reading comprehension in 102 typically developing students at three-time points (i.e., 8, 9, and 11 years of age). At each time point, working memory predicted unique variance in reading comprehension after controlling for other important factors (e.g., basic wording reading ability, vocabulary, and verbal ability).

More recent studies have emphasized the role of cognitive flexibility in reading comprehension within clinical (Guajardo & Cartwright, 2016; Cartwright et al., 2016) and typically developing populations (Cantin et al., 2016). In a sample of 93 students 7-10 years of age, inhibition, cognitive flexibility, and working memory were found to mediate age differences in reading comprehension scores (Cantin et al., 2016). Both Guajardo and Cartwright (2016) and Carwright et al. (2016) found that cognitive flexibility accounted for unique variance in reading comprehension. Taking it a step further, Guajardo and Cartwright (2016) examined whether working memory and cognitive flexibility in 3 to 5-year-olds could predict later reading skills (i.e., pre-reading skills, reading awareness, and reading comprehension) at 6 to 9 years of age. Results revealed that cognitive flexibility scores at age 3 to 5 predicted reading comprehension scores at age 6 to 9. This finding is especially important as it supports both the concurrent and predictive relation between cognitive flexibility, an EF skill, and reading comprehension.

As previously mentioned, the literature appears to be rather sparse regarding the relation (concurrent or predictive) between EF and reading fluency. Rose and Rouhani (2012) explored this relation in 77 adolescents with dyslexia. Working memory was found to explain unique variance in oral reading fluency even after taking into account word reading skills. However, the interaction between working memory and oral reading fluency was explained by vocabulary scores. Thus, the influence of working memory on reading fluency in adolescents may depend on the student's level of vocabulary knowledge. Although participants in this study were adolescents, these findings are particularly relevant to the current study as few others have examined the relation between EF skills and reading fluency at any age.

In sum, research has provided evidence supporting predictive and concurrent relations between EF and overall reading achievement, using broad composite scores that comprise several reading skills (Best et al., 2011; Gathercole et al., 2006; Monette & Marie-Claude Guy, 2011) and reading comprehension (Guajardo & Cartwright, 2016; Cutting et al., 2009; Sesma et al., 2009). Research on the relation between basic word reading and EF have generated mixed findings with some studies finding a positive relation after controlling for reaction time, naming speed, and age (Messer et al., 2016), while others have not (Locasio et al., 2010). Additionally, the manner in which EF has been defined has varied across studies, with some examining only one EF skill (Rose & Rouhani, 2012; Gathercole et al., 2006; Best et al., 2011; Cain et al., 2004) and others examining various constellations of EF skills (Messer et al., 2016; Guajardo & Cartwright, 2016; Locascio et al., 2010; Cutting et al., 2009; Sesma et al., 2009). Furthermore, there appears to be limited knowledge regarding the unique relation between EF skills and reading fluency, especially during elementary school when reading skills are under rapid development. To my knowledge, only one study to date has examined a relation between an EF skill (i.e., working memory) and reading fluency and that work was conducted with an adolescent population (Rose & Rouhani, 2012). Therefore, it is imperative to investigate a more comprehensive view of this complex construct as we turn our attention to its overlooked role in supporting reading fluency.

Purpose of the Study

The purpose of this study was to examine the role of EF skills in supporting the development of reading fluency in elementary school students with dyslexia. In doing so, this work expanded upon the current literature in several important ways. The vast majority of previous research on this topic has examined one or two EF skills with reading, particularly basic word reading or reading comprehension. The current study endorsed a more comprehensive view of EF by incorporating the three skills commonly agreed upon in the literature, namely working memory, cognitive flexibility, and inhibition. Research suggests that students with dyslexia demonstrate deficits on EF tasks compared to typically developing peers (Reiter et al., 2005; Cutting et al., 2009; Locasico et al., 2010; Cartwright et al., 2016) and that dysfluency at the text-level is a common area of difficulty for students with dyslexia (Shaywitz, Morris, & Shaywitz, 2008; Meisinger et al., 2010). It is essential to understand the core neuropsychological basis of reading fluency in this population. Therefore, this work filled gaps in the literature by examining the concurrent and predictive relation between EF skills and reading fluency, an area of reading that has received scant attention.

To this end, the short-term longitudinal relations between EF and reading fluency skills in a clinical sample of elementary school students with dyslexia was examined. Latent growth curve modeling was used to examine the following questions (see Figure 1).

1. Does EF predict initial (i.e., fall) reading fluency scores?
2. Does EF predict growth in reading fluency across a school year?

3. Does initial reading fluency performance predict subsequent growth in reading fluency across a school year?

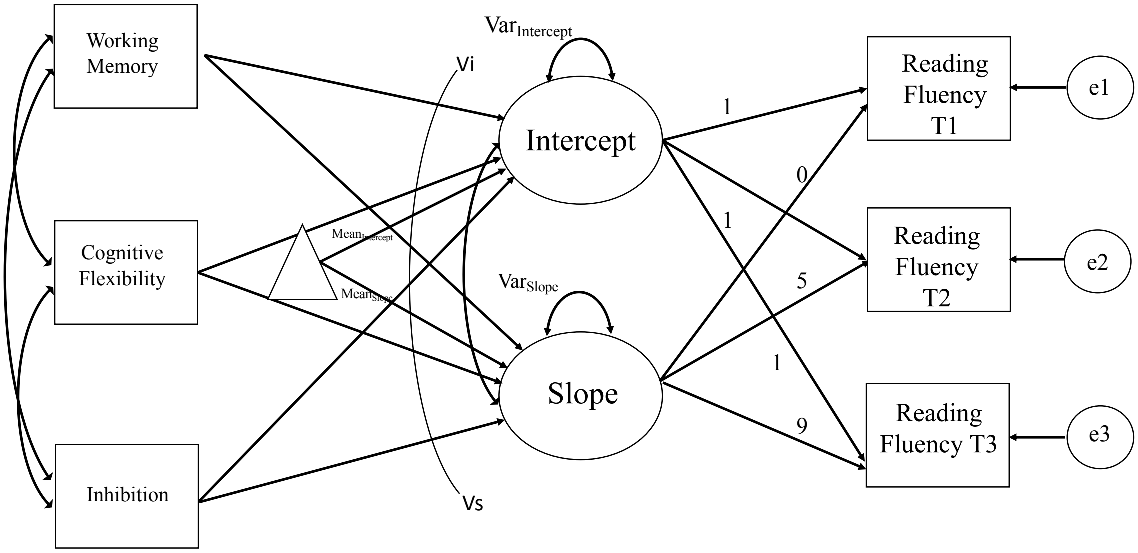

Figure 1.

EF predicting growth in oral reading fluency across a school year

Note. T1= timepoint one/fall, T2= timepoint two/winter, T3 = timepoints three/spring.

Method

Participants

Participants were 47 students attending a private school in the Mid-South region of the United States that provides an intensive day-treatment program for students diagnosed with dyslexia. Students were in the second grade (*n*=15), third grade (*n*=12), fourth grade (*n*=11), fifth grade (*n*=7), and sixth grade (*n*=2). These participants represent a subgroup of a larger longitudinal study investigating reading fluency development in students with dyslexia. Students were approximately 86% European American, 8% African American, and 6% other;

approximately 50% of the students were boys. Before school admission, students were identified as having a specific learning disorder in reading according to the criteria listed in the Diagnostic and Statistical Manual, Fifth Edition (DSM-5; American Psychiatric Association 2013). School records indicated that many students had been diagnosed with an educationally relevant comorbid diagnosis. Approximately, 39% of the students had attention-deficit/hyperactivity disorder (ADHD), 38% had a Specific Learning Disability (SLD) in written expression, 17% had an SLD in mathematics, and 16% of the students had a speech and language impairment.

Procedure

This study was approved by the University of Memphis Institutional Review Board (IRB #3814). Written parental consent and student assent were obtained before testing. The Read Naturally grade-level benchmark passages will be administered by the classroom teacher in the fall (August), winter (January) and spring (May) of the 2017-2018 school year. All EF measures were individually administered in the fall (August) by graduate students in school psychology with experience in standardized testing and specialized training in neuropsychological testing. Before data collection, assessors practiced test administration until a minimum of 95% agreement was reached. All the EF testing sessions were audio recorded to ensure accuracy, and 100% of the protocols were scored by a blind reviewer to determine inter-scorer agreement using Cohen's kappa with values ranging from .96 to 1.00. Individualized testing occurred in a quiet location in the school and was comprised of two testing blocks lasting approximately 30 minutes each. One block included the executive function measures used in the study, whereas the other block included a variety of reading skill measures that are outside the scope of the current investigation. To prevent fatigue, testing blocks were administered on separate days. The administration order of testing blocks was counterbalanced across participants, such that half received block one first and the other half received block two first. Within each block, measures were also administered in a counterbalanced order. Students were given a small prize (e.g., small eraser, pen, pencil, plastic figurine, sticker, etc.) for their participation in the study.

Measures

Executive Function Measures. Due to the developmental nature of EF, only norm-referenced clinical assessments that control for age were selected for use in this study (Tsujimoto, 2008; Best & Miller, 2010; Xu et al., 2013; Jurado & Rosselli, 2007).

Working Memory. Working memory was measured using portions of the Digit Span Subtest from the Wechsler Intelligence Scale for Children-Fifth Edition (WISC-V; Wechsler, 2014). The Digit Span subtest consists of several tasks that require unique skills. Digit Span Forward is a measure of short-term memory that requires an individual to listen to a series of numbers and then verbally repeat the list of numbers back in the same order they were presented. Digit Span Backward is a measure of working memory that requires an individual to listen to a series of numbers read by the examiner and then verbally repeat the list of numbers back in reverse order from which they were presented. Raw scores for Digit Backward will be converted to Scaled Scores using normative means and standard deviations. The Digit Span Backward task requires mental manipulation by the participant and is a commonly used measure of working memory (Cutting et al., 2009; Locasico et al., 2010; Guajardo & Cartwright, 2016; De Franchis et al., 2017). According to the WISC-V technical manual, test-retest reliabilities were .89 to .93 for students six years of age to 13 years of age (Wechsler, 2014).

Additionally, test-retest reliability coefficients for special groups were provided. Test-retest reliability coefficients of .83 for students with a specific learning disability (SLD) in reading and .93 for students with an SLD in reading and writing were reported. The Digit Span subtest was found to correlate (r = .78) with the overall working memory composite.

Inhibition. Inhibition was assessed by the Stroop Color and Word Test Children's Version (Golden, Freshwater, & Golden, 2003) and is composed of three subtests (i.e., Word, Color, and Color-Word). During the Word subtest, participants are instructed to read lists of color words (e.g., red, blue, and green) printed in black ink as quickly as they can for 45 seconds. For the Color subtest, participants are given lists of stimuli (e.g., xxxx) printed in different colors. Participants are asked to name the color of the stimuli as quickly as they can for 45 seconds. During the Color-Word subtest, participants are again given lists of color words. However, the word is printed in an ink color that is not congruent with actual word. For example, a student may see the word "blue" printed in red ink. Participants are asked to ignore the word and only name the color of the words as quickly as they can for 45 seconds. On all three tasks, if a student makes an error, then the examiner provides immediate feedback (i.e., no) and the student must correct their response before moving on to the next item. Raw scores for each subtest represent the number of responses (e.g., reading the printed word, naming the color of stimuli, or naming the color of ink the word is printed in) in the 45 seconds. Errors are not directly represented in the raw score, as the student is required to stop and correct errors as they go accruing penalties in the form of increased elapsed time. Additionally, an interference score will be derived by subtracting the Color subtest raw score from the Color-Word subtest raw score. A T-score (*M* = 50, *SD* = 10) generated from the interference score will be utilized as the primary measure of inhibition. Test-retest reliabilities for the three tasks are the following: Word (.86), Color (.82), and Color-Word (.73). Results from classification analysis suggested that scores discriminated between students with reading deficits and typically developing students. Classification accuracy was 100% for typically developing students, and 77% for students with reading disabilities, yielding a discriminant function coefficient of .63 (Golden et al., 2003).

Cognitive Flexibility. The Trail Making Test A & B (TMT; Reitan, 1971) is a measure of cognitive flexibility, focused attention, and motor speed. The task consists of two conditions that vary in difficulty. Trails A is a measure of visual scanning and requires participants to look at a page full of numbers and connect the numbers in numerical order. Trails B is a switching task where participants are asked to alternate between numbers and letters in sequential order (e.g., 1-A, A-2, 2-B, B-3, 3-C, and so on) and will be used as a measure of cognitive flexibility in this study. In a sample of 59 children, Neyens and Aldencamp (1996) reported 0.56 as the test-retest reliability coefficient for part B (.56), while others have noted a test-retest coefficient of .20 for children ages 8-19 on The Delis-Kaplan Executive Function System (D-KEFS; Delis et al., 2001). Furthermore, research has noted significant differences between students with reading problems and typically developing children on part B, potentially due to issues with sequencing (Narhi, Ransanen, Metsapelto, & Ahonen, 1997). The current study will utilize norms from Anderson et al. (1997). Raw scores (i.e., the amount of time to complete the task) will be transferred to a z score ($M = 0, SD = 1$) for part B. Since scores incorporate a time component, with lower times indicating increased cognitive flexibility, z scores will be reversed where more time results in a lower z score.

Reading Fluency Measure. The Benchmark Assessor Live program (Read Live, 2012) will be used to assess student's growth in reading fluency across the year. To monitor student progress, a set of 3 grade-level benchmark passages are administered in the fall, winter, and spring. Students may read the grade-level passages on a computer screen or in hard copy or printed form, although computer administration is typical in the school where this data was collected. However, during fall 2017, two classrooms read each reading probe on a printed paper version due to computer malfunctions. All other students were administered each reading probe from the computer screen for winter and spring 2018; students will read each reading probe from the computer screen. To ensure similarity across paper and computer administration, fall 2107 paper scores will be correlated with both winter and spring 2018 scores. During the passage reading, the teacher follows along indicating errors (i.e., missed words) and marks the last word read after 60 seconds have passed. Each passage produces one score (i.e., words correct per minute). These grade-level reading passages were extensively field-tested to confirm that each grade-level passage was similar in difficulty (Read Live, 2012). Results of field testing were compared to the first edition of the program. Passages that were not at the expected grade level were replaced or rewritten. Test-retest reliabilities for the three benchmark passages were conducted at three-time points (e.g., later on, the same year of initial testing, one year later, and more than a year between testing) yielding reliability coefficients of .915, .896, and .866, respectively (Read Live, 2012). The Benchmark Assessor Live data was compared to several high-stakes reading measures (e.g., Iowa Test of Basic Skills, Comprehensive Test of Basic Skills, and Gates MacGinitie Reading Tests) and an average validity correlation coefficient across grades and measures was .73.

Analytic Approach

Analyses were performed using Mplus 7.44 (Muthén & Muthén, 2014). Data were screened for unexpected or out of range values, outliers, univariate and multivariate normality, and missing data points. No univariate outliers were identified (*z*-scores < |3.29|; Tabachnik & Fidell, 2012), and univariate skewness and kurtosis statistics fell within acceptable limits (values < |2.0|; Tabachnick & Fidell, 2012). Further, evidence, via visual inspections of plots, did not suggest that the assumptions of linearity or homoscedaticicity of residuals were violated. Full Information Maximum Likelihood estimation with robust standard errors and scaled chi-square statistics was used to estimate missing data (i.e., eight reading fluency scores in fall). During the course of the study, one class experienced a computer malfunction and reading scores were not recorded at one time point. Little's MCAR test was significant, χ^2 (5, N = 47) = 19.061, p = .002, suggesting that the data were not missing completely at random. This finding is not surprising given that the missing data were nested within the same grade-level; however, the computer malfunction itself was random. Therefore, given the circumstances, it seemed reasonable to proceed with the assumption that the data were missing at random (Muthén & Muthén, 1998, 2012).

The present study had a relatively modest sample size of 47 school-aged participants (i.e., 2nd to 6th grade) and utilized Linear Latent Growth Curve Modeling (LGCM) to address the proposed research questions. Although guidelines have been advanced regarding sample size requirements for structural equation modeling (SEM), such as having five to 10 participants per estimated parameter (Bentler & Chou, 1987), MacCallum, Widaman, Zhang, and Hong (1999) noted that the interplay of several characteristics (e.g., sample size, communality across variables, and degree of factor determinacy) contributes to model fit and accuracy of parameter estimates. Further, Muthen & Muthen (2002) posit that LGCM may be conducted with a minimum sample of 40 participants. Thus, sample size should not be the only factor that should be considered in determining whether a particular LGCM analysis may be conducted (Wolf et al., 2013).

LGCM was conducted using a two-step process. The first step consisted of comparing alternative change models (i.e., intercept, linear, quadratic, and piecewise) to determine the model that best represents change over time. The intercept model compares the average scores at one time point (i.e., baseline), whereas the linear model represents growth between two time points. The quadratic model represents growth that changes non-linearly as a function of time. In contrast, a piecewise model yields information regarding rate of change across two time points (i.e., early learning; time point 1 to time point 2 and late learning; time point 2 to time point 3), which provides more utility for responder-status. When evaluating models in structural equation modeling, parsimony is typically preferred. Therefore, when comparing fit statistics to determine the best fitting model, it is standard to begin with the simpler models and then advance to more complex models. Once the best fitting change model was accepted, the second step involved adding EF variables (i.e., working memory, cognitive flexibility, and inhibition) to the model to see if they predicted change over time in the outcome variable (i.e., oral reading fluency). For the current study, all variables were continuous, and time was coded as months between each interval (0, 5, 9).

Several key indices were used to evaluate the models' goodness of fit including the model chi-square (χ^2), the Bentler comparative fit index (CFI), the Steiger-Lind root mean square error of approximation (RMSEA) with its 90% confidence interval, and the standardized root mean square residual (SRMR) (Boomsa, 2000; Mcdonald & Ho, 2002). The χ^2 statistic is sensitive to sample size and is considered a badness of fit test. Therefore, a non-significant *p*-value indicates a better fitting model. RMSEA is a formula that corrects for model complexity that favors parsimony and also considers sample size (Raykov & Marcoulides, 2000), with better fit indicated as values approach zero. RMSEA values $\leq .05$ indicate an excellent model whereas values $\geq .10$ suggests a poor fit. Further, it is important to examine the 90% confidence interval of the RMSEA value, as values $\leq .05$ indicate the studies model has a close approximation with the population (Browne & Cudeck, 1993; Hu & Bentler, 1999). The CFI is incremental fit index that compares a researcher's model with a baseline model. Regarding the CFI, a value of .90 or higher indicates a reasonably good fit and values exceeding .95 indicate an excellent fit (Hu & Bentler, 1999). The SRMR is a measure of the overall differences amongst the observed and predicted correlations; values < .10 are considered acceptable and a good fit is indicated by values < .08 (Hu & Bentler, 1999). Lastly, when comparing the BIC values of competing, non-nested models, less than a two-point reduction is considered weak, a two and six-point reduction is considered positive, a six and ten-point reduction is considered strong, and more than a ten-point reduction provides stronger evidence for a better fitting model (Kass & Raftery, 1995).

Results

Correlations, means, and standard deviations for each predictor variable are represented in Table 1. The present study examined four competing change models (i.e., intercept, linear, quadratic, and piecewise) to determine the best representation of change in reading fluency scores across the school year (see Table 2). The fit indices for the intercept model, $\chi^2 = 86.052$ ($df = 1$, $p < .001$), RMSEA = .661(CI .543-.786), CFI =.342, SRMR= .857, revealed an overall poor fit. Similarly, the linear model, $\chi^2 = 2.172$ ($df = 1$, $p = .140$), RMSEA = .158 (CI .000-.455), CFI =.991, SRMR= .031, revealed overall poor fit. The fit indices suggested that both the quadratic and piecewise models, $\chi^2 = 0.000$ ($df = 0$, $p < .001$), RMSEA =.000 (CI .000-.000), CFI =1.000, SRMR= .000, had excellent fit as these models were just-identified. Additionally, there was less than a two-point difference between the models in terms of BIC values, which suggested comparable fit. Although parsimony is an important consideration in evaluating structural equation models, it is also prudent to take into account how models align with theory. The quadratic model provided information about how the rate of change might accelerate or decelerate with the passage of time, whereas the piecewise model addressed the rate of change across two time points (i.e., early learning; time point 1 to time point 2 and late learning; time point 2 to time point 3). Since both models (i.e., quadratic and piecewise) provided excellent fit, the model that made the most sense theoretically was chosen. Therefore, the piecewise model was accepted as a better representation for the aforementioned research questions as it provided more utility for responder-status across the school year. It is notable that in the piecewise model, the intercept (variance = 495.044, $p < .001$), slope 1 (variance = 4.119, $p < .001$), and slope 2 (variance = 6.770, $p < .001$) variances were significant, indicating variability within the sample at each time point. Further, the intercept (M = 54.703, p < .001*),* slope 1 (M = 3.225, $p < .001$), and slope 2 (M = 3.931, $p < .001$) means were significant, indicating change across the school yea

Table 1

Correlations, Means, and Standard Deviations of the Motivation and Reading Skill Variables

	RF1	RF2	RF3	WM	CF	IH	*M*	*SD*
RF1	1.00	--	--	--	--	--	60.00	19.70
RF2	0.86**	1.00	--	--	--	--	70.83	22.84
RF3	.70**	.89**	1.00	--	--	--	86.55	23.76
WM	.32*	.18	.18	1.00	--	--	42.06	9.49
CF	.080	-.03	.050	-.01	1.00	--	43.76	11.88
IH	-.23	-.31*	-.23	.09	.23	1.00	50.15	8.40

Note. RF = reading fluency, WM = working memory, CF = cognitive fluency, IH = inhibition. The number following each abbreviated variable (RF) represents the time point of data collection. * $p < .05$. ** $p < .01$.

Table 2

Fit Statistics for Unconditional (Base Models)

Model	BIC	X^2(*p*-value)	RMSEA (90% CI)	CFI	SRMR
Intercept	1193.149	86.052 (<.001)	.661 (0.543-0.786)	.342	.857
Linear	1100.015	2.172 (0.140)	.158 (0.000-0.455)	.991	.031
Quadratic	1101.778	0.000 (<.001)	.000 (0.000-0.000)	1.000	.000
Piecewise Growth	1101.778	0.000 (<.001)	.000 (0.000-0.000)	1.000	.000

Note. BIC = Bayesian information criterion ; RMSEA = Steiger-Lind root mean square error of approximation; CI = confidence interveal, CFI = Bentler comparative fit index; SRMR = standardized root mean square residual.

For the second step, predictor EF variables (i.e., working memory, cognitive flexibility, and inhibition) were added to the piecewise model to see if these variables could account for the observed variability in the current sample. Fit indices supported an overall excellent model fit, $\chi^2 = 0.000$ ($df = 0$, $p < .001$), RMSEA = .000 (CI .000-.00), CFI = 1.000, SRMR = .000, as the base model was just-identified. Parameter estimates for the model are displayed in Table 3. Regarding the first research question (i.e., does EF predict fall reading fluency scores), results indicated that only inhibition was a significant predictor of reading fluency at baseline. A one unit increase in inhibition scores predicted a 0.825 decrease in reading fluency scores at baseline. That is, better inhibition was associated with less fluent reading in the beginning of the school year. Regarding the second research question (i.e., does EF predict growth in reading fluency across the school year), no EF variables emerged as significant predictors of growth in reading fluency across the school year at either slope. In other words, executive function (i.e., working memory, cognitive flexibility, and inhibition) did not predict growth across the fall semester (i.e., early learning) or across the spring semester (i.e., late learning). Regarding the third research question (i.e., do baseline reading fluency scores predict subsequent growth in reading fluency across the school year), results indicated that the intercept did not emerge as a significant predictor of either slope. In other words, initial reading scores at the beginning of the school year do not predict the amount of growth across the fall or spring semesters. However, baseline reading scores (i.e., the intercept) approached significance for slope 1 ($p = 0.077$), early learning across the fall semester, and may emerge as a significant predictor with a larger sample size.

Table 3

Parameter Estimates for All Predictor Variables on Intercept and Slopes

	Estimate	S.E.	Est./S.E.	*p*-value
Intercept ON				
Working Memory	0.343	0.346	0.991	0.322
Cognitive Flexibility	0.072	0.207	0.349	0.727
Inhbition	-0.825	0.404	-2.041	0.041
Slope 1 ON				
Working Memory	0.039	0.036	1.093	0.274
Congitive Flexibility	0.007	0.022	0.334	0.738
Inhibition	-0.041	0.030	-1.373	0.170
Slope 2 ON				
Working Memory	0.011	0.038	0.295	0.768
Cognitive Flexibility	0.034	0.025	1.384	0.166
Inhibition	0.022	0.040	0.543	0.587
Slope 1 ON				
Intercept	-0.026	0.014	-1.769	0.077
Slope 2 ON				
Intercept	-0.018	0.015	-1.206	0.228
Slope 1 WITH				
Slope 2	0.260	0.691	0.377	0.707

Note. Slope 1 is considered early learning (i.e., growth from fall to winter) and Slope 2 is considered late learning (i.e., growth from winter to spring).

Discussion

The goal of the present study was to examine the relation between EF skills (i.e., working memory, cognitive flexibility, and inhibition) and oral reading fluency at the connected text level in a clinical sample of students diagnosed with dyslexia. Specifically, the present study aimed to examine these potential relations concurrently and predictively across a school year. Overall, results from the study indicated that EF skills (i.e., working memory, cognitive flexibility, and inhibition) did not significantly predict growth in reading fluency scores across the school year, and only inhibition emerged as a significant predictor for baseline reading fluency scores in the fall. However, it is not clear whether these results represent an accurate portrayal of the relations among EF skills and reading fluency due to methodological limitations associated with the available sample size. In particular, concerns regarding statistical power and collapsing student data across grade levels complicates the interpretation of these results.

To best of my knowledge, only one study to date (Rose & Rouhani, 2012) has examined the relation between reading fluency, at the connected text level, and executive function in a sample of students with dyslexia. Therefore, it was important to examine both the concurrent and predictive relation among these variables. The first research question posed in this study (i.e., does EF predict fall reading fluency scores) addressed the former and the second research question (i.e., does EF predict growth in reading fluency across a school year) addressed the latter. In this study, only inhibition emerged as a significant predictor for baseline reading fluency scores in the final model, with higher inhibition scores resulting in lower reading fluency scores. The direction of the relation between inhibition and reading fluency was unexpected, as most previous studies have found a positive relation between inhibition and reading skills (Gathercole et al., 2006; Messer, 2016) and others have found no relation (Locascio, 2010;

Monette & Marie-Claude Guy, 2011). One possibility for the present findings may be explained by the measure (i.e., Stroop Color-Word task) utilized to measure inhibition. The Stroop Color-Word task assumes that participants are automatic readers and automaticity is necessary for interference to occur). Children who have not developed as fully automatic readers may not be able to read the words on the Stroop Color-Word task with automaticity, resulting in more attention directed toward the color of the word instead of the word itself. Consequently, students with less automaticity for words presented during the Color Word task may experience less interference, resulting in higher scores. Another possibility may be that children with more developed inhibition take the time to decode unknown words accurately instead of providing prepotent responses (e.g., reading adjunct as adjective). A third possibility may be that methodological limitations (e.g., not being able to parse the sample by grade) contributed to the negative relation between inhibition and reading fluency in the present study. Development may be a particularly important variable for students with dyslexia. For example, a student in fifth grade may have higher inhibition scores but still struggle to read fluently because of the underlying neurodevelopmental disorder, dyslexia. Whereas, a student in second grade may have developed inhibition but may have not mastered basic word reading skills, which affects his or her ability to read fluently.

Also unexpected was the lack of a relation between the other two EF skills (i.e., working memory and cognitive flexibility) and reading fluency. Prior research has supported a relation between EF and other reading skills, specifically reading comprehension and basic word reading. (Cartwright et al., 2016; Cutting et al., 2009; Guajardo & Cartwright, 2016; Locascio et al., 2010 Messer et al., 2016). Although the relation between EF and reading comprehension is well supported in literature, findings regarding the relation between EF and basic word reading has varied (Messer et al., 2016; Locascio et al., 2010).That is, some authors found a positive relation between EF and basic word reading (Messer et al., 2016; Locascio et al., 2010) and some have not found a relation between these two constructs (Sesma et al., 2009). Regarding research examining the relation between EF and reading fluency, Rose and Rouhani (2012) explored the relation between working memory and reading fluency in an adolescent population with dyslexia. Working memory was found to account for unique variance in reading fluency scores after controlling for basic word reading; however, the relation was accounted for by vocabulary scores.

One possibility for the present results indicating a non-significant relation between some EF skills (i.e., working memory and cognitive flexibility) and reading fluency may be due to methodological issues (i.e., the limited sample size precluded the examining of developmental level). Since EF is under a considerable state of maturation neuroanatomically and cognitively (Tsujimoto, 2010), it may be prudent to consider age, or developmental level, as a potential factor that may influence the relation between EF and reading fluency. EF could be more important for reading fluency skills in older student populations, once both skills are fully maturated and as the text requirements become more challenging. Lastly, the statistical analyses employed in this study may have been underpowered, due to sample size, adversely impacting the likelihood of detecting a relation between EF and reading fluency. As discussed in the method section, clear rules do not exist regarding the number of participants required to conduct a LGCM, with some suggesting five to 10 participants per path (Bentler & Chou, 1987) and others positing a minimum sample of 40 participants (Muthen & Muthen, 2002). While the current sample size surpassed the minimum recommendations suggested by Muthen & Muthen, (2002), the sample size used in this study was lower than typical for this specific analytic technique. In the present study, correlational analyses revealed a significant positive relation between working memory and reading fluency scores at one time point, which indicates a need to explore this relation further in a larger sample.

Another possibility may be that working memory and cognitive flexibility predict some reading skills more than others. Previous research on the relation between working memory and cognitive flexibility and reading fluency (Rose & Rouhani, 2012) is rather sparse compared to other reading skills, namely basic word reading (Messer, Henry, & Nash, 2016; Locascio et al., 2010) and reading comprehension (Cartwright et al., 2016; Cutting et al., 2009; Guajardo & Cartwright, 2016). While reading skills are interrelated (i.e., lower-level skills are used to support higher-level skills), they are distinct in nature (Cutting et al., 2009). Thus, it is difficult to determine if the results of the present study are similar to what would be expected, since the literature exploring these constructs in relation to reading fluency in students with dyslexia is sparse.

To the best of my knowledge, this is the first study to explore the predictive relation between EF and reading fluency scores in as sample with students diagnosed with dyslexia across a school year. However, others have explored EFs' contribution to later reading skills. Monette & Marie-Claude Guy (2011) investigated the predictive relation between EF measured in kindergarten and basic word reading measured at the end of first grade in a typically developing population. A unique, predictive relation was found between EF and both word reading and spelling scores. However, in the current study none of the EF variables were found to predict growth in reading fluency across the school year. One possible explanation for these null results is that EF skills may be more impactful at the word level for certain age groups. For example, a primary goal during first grade is learning to decode words accurately, whereas, the focus of reading shifts during second and third grade to developing as fluent readers. Unfortunately, the small sample size in this study prevented exploring the impact of EF at different developmental levels (e.g., early to late elementary grades). Other potential factors that may influence the present findings, mentioned earlier, include limited sample size and the lack of a comparison group of typically developing students.

The third research question posited by this study addressed whether baseline reading fluency scores would predict subsequent growth in reading fluency across the school year. Research has demonstrated that initial reading skills are an important predictor of subsequent growth throughout the school year (Speece & Ritchery, 2005; Stage & Jacobsen, 2001; Stage, Sheppard, Davidson, & Browning, 2001). Surprisingly, reading fluency skill at the beginning of the school year did not predict reading fluency growth across the fall semester (i.e., early learning) or spring semester (late learning). However, baseline reading scores approached significance ($p = .077$) as a predictor for early learning across the fall semester. It seems likely that baseline reading fluency scores would emerge as a significant predictor with a larger sample size. Students typically show patterns of more robust growth across the fall than the spring semester in reading fluency as measured by curriculum-based measures (Christ, Silberglitt, Yeo, & Cormier, 2010), which aligns nicely with baseline scores approaching significance as a predictor for early learning. Previous research has demonstrated differential rates (i.e., early versus later grades) of growth in reading fluency across grades (Silberglitt & Hintze, 2007). Therefore, using a larger sample and grouping students by grade level, instead of collapsing the data across grades, may yield more information regarding the complex relation between EF and oral reading fluency.

Theoretical Implications

It is important to consider the theoretical implications of the current findings. The EF skills (i.e., working memory, inhibition, and cognitive flexibility) used in the present study were selected based on the Miyake et al. (2000) model. Traditionally, EF has been described by unity and diversity (i.e., related but distinct skills) (Friedman & Miyake, 2017; Miyake et al., 2000). Therefore, it was expected that the three EF skills would correlate with each other; however, none of the EF skills were found to correlate significantly with one another in this study. Given the methodological limitations outlined in previous sections, conclusions based on the results of this study must be drawn with caution. It may be tempting to interpret these disparate results as pointing to diversity rather than to unity in terms of the relation among the EF skills comprising Miyake et al.'s (2000) unified theory of EF; however, the omission of development as a variable in addition to the small size of the sample seem like the more likely explanation.

Regarding reading, reading fluency is often conceptualized as the bridge between basic word reading and reading comprehension (Pikulski & Chard, 2005). Given the shortage of research that examines the relation between EF and reading fluency with students diagnosed with dyslexia, the present results are especially difficult to interpret. If relations between EF skills and other reading skills exist, and reading skills are associated with each other (i.e., lower-level skills support higher-level skills), one would expect that EF skills to also predict reading fluency, "the bridge." However, EF skills did not correlate with reading fluency in a consistent manner in this study. Cognitive flexibility did not correlate with reading fluency at all, whereas working memory and inhibition each correlated with reading fluency at a single time point, further complicating the results of the current study. Additionally, as aforementioned, initial reading scores typically predict later reading scores (Speece & Ritchery, 2005; Stage & Jacobsen, 2001;

Stage, Sheppard, Davidson, & Browning, 2001); however, baseline reading scores did not significantly predict either slope in the latent growth curve analysis. It is important to note that baseline reading scores were approaching significance as the $p < .05$ level for the first slope (early learning). More importantly, the relation was not what would be expected (i.e., a negative estimate) compared to previous findings. Research suggests that students often make the most substantial gains during the initial phase of remediation/intervention (Torgesen, 2005). It may be that students with the lowest scores are often new to the school, and are likely to make strong gains during the fall semester (i.e., early learning). In contrast, returning students who have already benefited from a year of remediation will likely have higher initial scores in the fall and may not show as robust growth. However, the sample size precluded the examination of this potentially important variable (i.e., remediation history). Overall, the current findings did not fully align with the theoretical foundations of either EF or reading fluency. It seems likely that methodological issues contributed to these divergent findings. Much more research is needed to elucidate the relation among EF and reading fluency.

Limitations and Future Research

While the results of this study are informative to the field of reading research, there are several methodological limitations related to the sample characteristics (including sample size), variable measurement, and the omission of relevant variables that warrant discussion. As previously noted, the sample size was relatively small ($N = 47$) and consisted of students with severe reading difficulties, and future studies should include a larger, more representative sample size of children with dyslexia. Participants were rather homogenous in terms of race/ethnicity (i.e., predominately White). Although data regarding socioeconomic status were not available, it is presumed that the majority of students were from relatively affluent families given the financial costs associated with enrollment in a private school. Dyslexia impacts individuals across race/ethnic groups membership and socio-economic status (Hoyles, & Hoyles, 2010). Additionally, participants in the current study attended a day treatment school that specializes in intervention for children with dyslexia. Future studies should examine the relation of these constructs in a public-school setting where students with a broader continuum of reading skills may be found. In sum, this work should be replicated with a more diverse sample of students with dyslexia to improve the generalizability of the results. Lastly, this study utilized a clinical population (i.e., children with dyslexia), yet so little is known about the relation between EF and reading fluency that studies with typically developing readers are also needed. Research has supported that individuals with a reading disability score lower on EF tasks than typically developing students (Cutting et al., 2009; Reiter, Tucha, & Lange, 2005). Therefore, it may be that students with dyslexia are performing lower than their typically developing counterparts on both reading and EF measures. As a future direction, it would be beneficial to include a comparison group comprised of typically developing readings.

Regarding measurement, only baseline executive function skills were utilized to predict growth in reading fluency scores. Due to the developmental nature of EF, it would be prudent to measure EF across multiple time points to allow for a more precise examination of how the relations between fluency and EF unfold. Further, a single indicator was utilized for each observed executive function skill. Future studies may use multiple indicators to create a latent construct. It may also be prudent to consider different approaches to measuring both reading fluency and executive function. Regarding reading fluency, this study utilized words correct per minute as the outcome variable. Although this is a commonly used metric within the response to intervention (RTI) literature, parsing reading fluency into its more specific components, rate and accuracy, may yield valuable information. Regarding EF, it may be beneficial to include both clinical and self-report measures to better account for growth in EF over time. Due to the potential impact of automaticity, it would be prudent to explore other methods of measuring inhibition than the Stroop Color-Word task.

Several potentially important variables may account for the relation between EF and reading fluency that were not examined in the present study (e.g., diagnosis of ADHD, phonological awareness, vocabulary knowledge, and intervention history). Jacobson et al. (2011) found a relation between working memory and reading fluency in a sample of students with ADHD. Due to the high comorbidity rate for ADHD and dyslexia (add supporting cite), future studies should assess for differences between students with comorbid diagnoses (i.e., ADHD and dyslexia) and those diagnosed only with dyslexia. Further previous research has supported relations between EF and reading skills initially; however, after controlling for important variables (i.e., phonological awareness and vocabulary knowledge), the relation was no longer significant (Locascio, 2010; Rose & Rouhani, 2012). The limited sample size simply did not allow for these potential covariates to be considered. However, future studies should consider these important factors when examining the relation between EF and reading fluency.

Conclusion

The relation between executive function and reading fluency is largely overlooked in the literature, especially in students with dyslexia. To the best of my knowledge, this was the first study to explore the concurrent and predictive relation between EF and reading fluency, and also the first to examine these relations with elementary school students diagnosed with dyslexia. The present study was also unique in that multiple EF skills (i.e., working memory, inhibition, and cognitive flexibility), consistent with Miyakee et al.'s (2000) model, were assessed. Over all, the study yielded null results regarding the predictive relation between EF and initial reading fluency scores on growth in reading fluency across a school year. Given the potential impact of methodological limitations on these results, conclusions from this study should be drawn with caution. However, this study highlights the need for additional research to elucidate the complex relation of executive function and reading fluency.

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