EXECUTIVE FUNCTIONS IN CHILDREN WITH READING DISABILITY

By

SARAH J. MCCANN

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Sarah J. McCann

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Reading disability is a neurologically-based developmental disorder characterized by a deficit in processing phonological information in language. Linguistic models suggest that deficits in lower-level processes, such as phonological processing, may greatly tax upper-level domains of executive function. Additionally, functional neuroimaging conducted during reading tasks suggest that children with reading disability have underactivation in posterior brain regions and a relative overactivation in anterior brain regions, specifically in the inferior frontal gyrus. In addition to phonological processing, the inferior frontal gyrus has been implicated in executive functions such as inhibition and set-shifting. However, few studies have specifically examined these executive functions in children with reading disability. Characterization of the executive functions in children with reading disability is an important first step in identifying potential subgroups of children who may require different intervention strategies to improve their reading skills.

The current pilot study examined executive functioning of children with reading disability (RD, n=11) and a control group of normal readers (control; n=8) using a battery of tests measuring different aspect of executive functions: inhibition (Color-Word Interference subtest from the D-KEFS), inhibition and shifting (WCST-64), attentional control and shifting (Creature

Counting and Opposite Worlds subtests from the TEA-Ch), verbal working memory (Numbers subtest from the CMS), and parent-reported behavioral inhibition, set shifting, and working memory (Inhibition, Shift, and Working Memory Indices from the BRIEF). The performance profile of RD group was qualitatively examined using norm-based standardized performance scores and quantitative group differences were explored between the RD and normal control group.

Qualitative evaluation of the RD norm-referenced performance profile revealed impairment in the inhibition and attentional control and shifting domain, but performance was within normal limits across the other domains of executive functioning. They were rated in the clinically significant range on the working memory index on the parent-report measure of EF. Quantitative group comparisons indicated that the RD sample performed worse than the control group in four of the five domains of executive functioning and were rated worse than controls on the shift index on the parent-report of EF. Implications and plans for continued data collection are discussed.

CHAPTER 1
INTRODUCTION

Executive functions, broadly defined, make up a cognitive domain comprised of related, yet distinct, abilities that enable intentional, goal-oriented, problem-solving. Executive functioning is thought to be an over-arching construct that consists of supervisory or self-regulatory functions, which direct and organize cognition, emotional response, and overt behavior (Gioia, Isquith, Kenworthy, & Barton, 2002; Denckla & Reader, 1993). The commonly agreed upon subdomains of executive functions include the ability to initiate and sustain behavior, inhibit competing stimuli, select relevant task goals, plan and organize problem-solving strategies, shift cognitive strategies when necessary, and monitor and evaluate one's behavior (Pennington & Ozonoff, 1996; Hayes, Gifford, & Ruckstuhl, 1996). Additionally, working memory and attention are commonly referred to as subdomains of executive functioning (Pennington, Bennet, McAteer, & Roberts, 1996). The current study focuses on three aspects of executive functions most relevant to the reading disability population under the proposed model: the ability to inhibit irrelevant stimuli or responses, hold and manipulate verbal information in working memory, and flexibly shift cognitive set when necessary.

Reading Disability

Reading Disability is a developmental disorder with neurological underpinnings, and is characterized by reading achievement (reading accuracy, speed, or comprehension) that falls substantially below that expected given the individual's chronological age, measured intelligence, and age-appropriate education (American Psychological Association, 1994). The term "reading disability" and "developmental dyslexia" are synonymous, as dyslexia is not a diagnosable disorder according to the Diagnostic Statistical Manual – 4th Edition (DSM-IV), but is the colloquial term for reading disability. Reading disabilities affect up to 5-10% of school-age children (American Psychological Association, 1994; Shaywitz *et al*., 2003), often causing significant disturbances in the child's school performance, or even leading to school failure (Shaywitz *et al*., 1998). Reading disabilities can negatively impact the child's self concept and self-esteem (Cooley, 2002). In spite of recent advances in the diagnosis and treatment of reading disabilities, many children with reading disability fail to receive the necessary academic support. One of the major difficulties with allocating appropriate services is the significant variability in treatment efficacy at the individual level. Although commonly co-occurring conditions such as attention deficit/hyperactivity disorder, anxiety, depression, and oppositional defiant disorder could account for some of this variability in outcomes continues to be unexplained even when these factors are controlled (Shaywitz & Shaywitz, 2005; Torgesen, 2004). To identify effective intervention and paths to prevention, the underlying cognitive mechanisms must be identified and understood.

Several theories of reading disability have been proposed, such as the rapid auditory processing theory (Tallal, Allard, Miller, & Curtiss, 1997), the cerebellar theory (Nicolson and Fawcett, 1990), and the phonological theory (Liberman, Shankweiler, & Liberman, 1998; Torgesen, 2004). The phonological theory is the most supported and widely accepted theory. The phonological theory posits that, in order to learn to read and utilize language effectively, one must recognize that that spoken words can be broken up into elemental units of sound (phonemes) and that the letters of the written word represent these sounds (Bruck, 1992; Shaywitz et al., 2003). This basic awareness is deficient in children and adults with reading disability. Several studies of young school aged-children have confirmed that a deficit in phonological awareness represents the best individual correlate of reading disability (Fletcher *et al*., 1994; Morris *et al*., 1998; Helland & Asbjornsen, 2000). These findings are also the basis for the most successful interventions designed to improve reading skills. These interventions most often include training in phonemic awareness, phonics, fluency, vocabulary, and comprehension (Report of the National Reading Panel, 2000; Torgesen *et al*., 1999).

A model based upon the phonological theory (Alexander & Slinger-Constant, 2004) indicates that reading is a multi-level process. According to this model, attention and arousal are necessary for consistent and accurate sensory input, and serves as the base level for this model. There are five processors, which create differing forms of sensory input. These processors include: orthographic, articulatory, phonologic, prosodic, and morphosyntactic. It is believed that children with reading disability are impaired in the orthographic, articulatory, and phonological processors, and therefore the output from these processors is less distinct than output from processors functioning at the normal level. The sensory input created by these lower-level processors is held briefly in short term memory and when processing must occur, working memory must become available. These holding systems of working memory have been found to serve as "slaves" for the central executive system, which is thought to develop strategies when there are roadblocks, organize information and plan action, and are responsible for self-monitoring and controlling intention and holding back from responding too quickly. Executive functions depend of sensory input and cortical representations being held in working memory long enough for processing. Increasing the burden on working memory resources may result in an increased difficulty in controlling inhibition (Bitan *at al*., 2005; Pennington, Bennet, McAteer, & Roberts, 1996). Therefore, attention, working memory, and executive functions are integral to each other for the accurate perception, processing, and production of language. Additionally, using a top-down perspective, the central executive system plays an important role in mediating the language processing system, so that if these functions are impaired, a child may have a harder time holding on to and processing linguistic information. Therefore, the child's impairment may be further manifested in phonological processing because of a deficit in the central executive system that is used for the management of lower-level processes.

Neurological Underpinnings of Reading Disability

Converging evidence from a number of studies using several different brain imaging techniques [functional magnetic resonance imaging (fMRI), positron emission topography (PET), and magnetoencephalography (MEG)] indicates that successful reading involves a left hemisphere posterior reading system that consists of both ventral and dorsal components and frontal regions (e.g., the inferior frontal gyrus) (Pugh *et al*., 2001; Hickok & Poeppel, 2004). See Figure 1-2.

Findings from several studies suggest these circuits to be dysfunctional in children with reading disability (Shaywitz *et al*., 1998; Frackowiak, Friston, Frith, Dolan, & Mazziotta, 1997; Pugh *et al*., 2000). For instance, Shaywitz et al. (2003) found significant differences in brain activation during phonological analysis compared to normal readers. Specifically, nonimpaired readers demonstrated significantly greater activation compared to impaired readers in left hemisphere sites including the inferior frontal, superior temporal, parieto-temporal and middle temporal gyri. These findings further support the report from many researchers using neuroimaging indicating children with reading disability exhibit a failure of left hemisphere brain systems to function properly while processing linguistic information (Brunswick, 1999; Temple *et al*., 2000) as well as during non-reading visual processing tasks (Demb, Boynton, & Heeger, 1998).

Several studies (Shaywitz et al., 1998; Shaywitz & Shaywitz, 2005; Pugh *et al*., 2000) posit that children with reading disability utilize compensatory systems located in bilateral anterior sites, specifically in the inferior frontal gyrus (IFG) in response to left hemisphere weakness. For instance, nonimpaired readers showed increased bihemispheric inferior frontal gyrus and prefrontal dorsolateral activation during non-word reading compared to non-impaired readers (Shaywitz *et al*., 1998). The IFG is typically known as Broca's area, and is involved in phonological processing. Therefore, researchers have hypothesized that the increased activity in the IFG in children with reading disability reflects an increased reliance on this region to phonological processing in an attempt to cope with the demands of phonological analysis (Pugh *et al*., 2000; Shaywitz & Shaywitz, 2005).

Frontal Lobe Systems, the Inferior Frontal Gyrus, and Executive Functions

The phrase "frontal lobe system" refers to the actual prefrontal cortex in conjunction with the areas of the thalamus and basal ganglia and those parts of the limbic system that are relevant to the affective aspects of executive functions. The current study utilizes neuropsychological assessments to measure performance on tasks that have been shown, via neuroimaging, to activate the IFG located within the frontal lobe region. The cognitive domains of working memory, inhibition, and set-shifting have been identified as three domains of executive functions that have been linked to prefrontal activation, specifically the IFG (Roberts, 1994). For instance, in a study by Buchsbaum et al., (2005), 30 normal participants completed the Wisconsin Card Sorting Task (WCST) while in a functional MRI (fMRI). The Wisconsin Card Sorting Task is a common measure of executive functions, and involves the ability to form abstract concepts, to sustain attention, and to shift cognitive sets flexibly in response to varying conceptual rules, while simultaneously inhibiting incorrect responses (Tsuchiya, Oki, Yahara, & Fujieda, 2004; Aron, Robbins, & Poldrack, 2004). Buchsbaum *et al*. (2005) found strong bilateral IFG activation temporally related to set-shifting and set maintenance within the task. Additionally, Aron *et al*., (2004) found bilateral IFG activation using fMRI while participants completed a stop-signal task, as task traditionally used to assess inhibitory ability. Furthermore, increasingly taxing the working memory resources leads to an increased difficulty in controlling inhibition (Bitan *et al*., 2005; Pennington, Bennet, McAteer, & Roberts, 1996). Thus, working memory, inhibition, and set-shifting have been identified as three dimensions critical for understanding the breadth of executive function tasks.

The sections that follow summarize the existing literature regarding the executive functioning performances of children with reading disabilities across components of verbal working memory, inhibition, set-shifting, and parent ratings of behavior. The current study is the first study of reading disability to examine an attentional control/shifting subdomain as a component of executive functions.

Working Memory

Working memory allows for a finite amount of information to be actively maintained and manipulated (Baddeley, 1986, 1992), and may serve as a mechanism for higher cognitive processes, such as problem-solving, reasoning, decision-making, and language comprehension (Jonides, 1995). Baddeley’s tripartite model of working memory posits that it is not a unitary system, and instead proposes two separate “slave systems” for the short-term maintenance of information (one for verbal information and one for visual information) and one central executive system for the supervision and information integration of the other systems (Baddeley, 1992, 1996). The articulatory loop is one of the “slave systems” that uses primarily phonological information (verbal) and prevents its decay by refreshing its contents through articulatory rehearsal (subvocal repetition). The visuo-spatial sketchpad is the second “slave system”. Its purpose is to store visual and spatial information.

It is posited that children with reading disability have impairment in the articulatory loop component of working memory, and therefore show deficit in verbal working memory tasks (Kibby, Marks, & Morgan, 2004). Verbal working memory appears important in the ability to hold sounds and words in mind as well as content while reading a passage. Digit Span Tasks are commonly used to assess verbal working memory. These tasks provide a measure of immediate recall, particularly attention and short-term memory with the digits forward component; however the digit span backward task is more of a working memory test because it requires manipulation, or reorganization, of the information (Lezak, 1995; Sattler, 1988). In general, marked deficits have been found in children with reading disability in verbal working memory (Wilcutt, *et al*., 2002; Lezak, 1995; Reiter, Tucha, Lange, 2005; Jeffries & Everatt, 2004; and Kibby, Marks, & Morgan, 2004).

Inhibition

Inhibition is a subdomain of executive functions that involves the ability to inhibit prepotent (or natural) responses and stop ongoing responses. Inhibition fundamentally contributes to the functioning of other executive functions, such as working memory (Barkley, 1992; Aron, Robbins, & Poldrack, 2004). Inhibitory processes are also important for the development of cognitive abilities such as learning, memory, and motor activity (Johnston & Blue, 2006). The domain of inhibition is most often assessed using a go/no-go paradigm or Stroop color-word task, which measures the ability of a participant to inhibit a well-learned response. Helland *et al*. (2000) and Wilcutt *et al.* (2005) found marked deficits in a group of children with reading disability on the Stroop Color/Word task and a Stop Signal task. However, several studies have failed to replicate these findings (Reiter, Tucha, & Lange, 2005).

Shifting

This suddomain of executive functions is commonly referred to as “set-shifting”, because this subdomain requires the ability to shift attention or shift between strategies or response sets (Baddeley, 1996; Monsell, 2003). Successful set-shifting involves the disengagement of an irrelevant task set or strategy and the consequent activation of a more appropriate one (van der

Sluis, de Jong, & van der Leij, 2004). Task-switching is subserved by other executive functions, particularly inhibition and working memory (Baddeley, 1996; Aron, Robbins, & Poldrack, 2004), and has been shown to have overlapping neural activation pathways utilized by working memory and inhibition (Aron, Robbins, & Poldrack, 2004; Bushbaum, Greer, Chang, & Berman, 2005; Demakis, 2003). Task-switching paradigms focus on the switching process by providing cues that inform the subject when to shift tasks, such as in the Wisconsin Card Sorting Task (Bushbaum, Greer, Chang, & Berman, 2005). Lazar (1998) and Zhang *et al*. (2004) found that a reading disability group performed significantly worse than controls on this task. However, several studies have failed to find deficits in this sub-domain in children with reading disability. However, these findings have not been consistently demonstrated on several scoring variables of the WCST-64 (Wilcutt, Pennington, Olsen, Chhabildas, & Hulslander, 2005; Narhi, Rasanen, Mesapelto, & Ahonen, 1997; Sengstock, 2001). There remain equivocal findings within this population as to whether impairments exist in this domain. Perhaps the difficulty lies in the failure to separate out the underlying deficit that may be causing the impairment because of the overlap in task specificity.

Attentional Control and Set-Shifting

Attentional control (which is also sometimes referred to as attentional shift or attentional flexibility) is defined as the ability to shift attention adaptively and flexibly (Manly, Robertson, Anderson, & Nimmo-Smith, 1999). Attentional control is therefore closely related to set-shifting and inhibition as outlined above. Much like its construct, tasks used to measure executive function (and therefore stated to measure attentional control) apply multiple cognitive components. Factor loading of subtests from the Test of Everyday Attention for Children (TEA-Ch; Manly, Robertson, Anderson, & Nimmo-Smith, 1999), suggest two subtests represent the domain of attentional control and switching, and are most likely also supported by the inhibition and verbal working memory domains.

Parent-rating Behavioral Measures of Executive Functions

Performance-based neuropsychological measures may yield a limited, incomplete assessment (Gioia & Isquith, 2002). While performance tests attempt to tap executive functions in explicit and specific ways, many confounds limit their ecological validity and generalizability (Gioia & Isquith, 2002). The Behavior Rating Inventory of Executive Function (BRIEF) – Parent-report is a measure of executive functions that yields two index scores, Behavioral Regulation and Metacognition, and eight subscale scores: Inhibit, Shift, Emotional Control, Initiate, Working Memory, Plan/Organize, Organization of Materials, and Monitor. Past research using the BRIEF – Parent-report has found children with dyslexia to receive significantly higher (reaching more clinical levels) scores than matched controls on the BRIEF Working Memory, Plan/Organize, and Monitor Scales. The reading disability group did not endorse more problem levels of the Inhibit, Shift, and Emotional Control Scales compared to normal controls (Gioia, Isquith, Kenworthy, & Barton, 2002). Thus, the proposed study also incorporates a parent-report measure of executive function in order to more completely assess executive function profiles in reading disability. Specifically, the current study will be examining the Inhibit, Shift, and Working Memory Indices from this measure.

Aims of the Current Study

The primary goals of the current study are to use a clinical assessment battery to learn more about the specificity of executive functions impairment in children with reading disability and to compare this profile of executive functions performance to a normal control group. Characterization of the executive functions in children with reading disability is an important first step in identifying potential subgroups of children who may require different intervention strategies to improve their reading skills.

Based on the literature and anecdotal observations, we hypothesized that the reading disability group would perform worse than controls in the domains of verbal working memory, inhibition, shifting, and attentional control and switching.

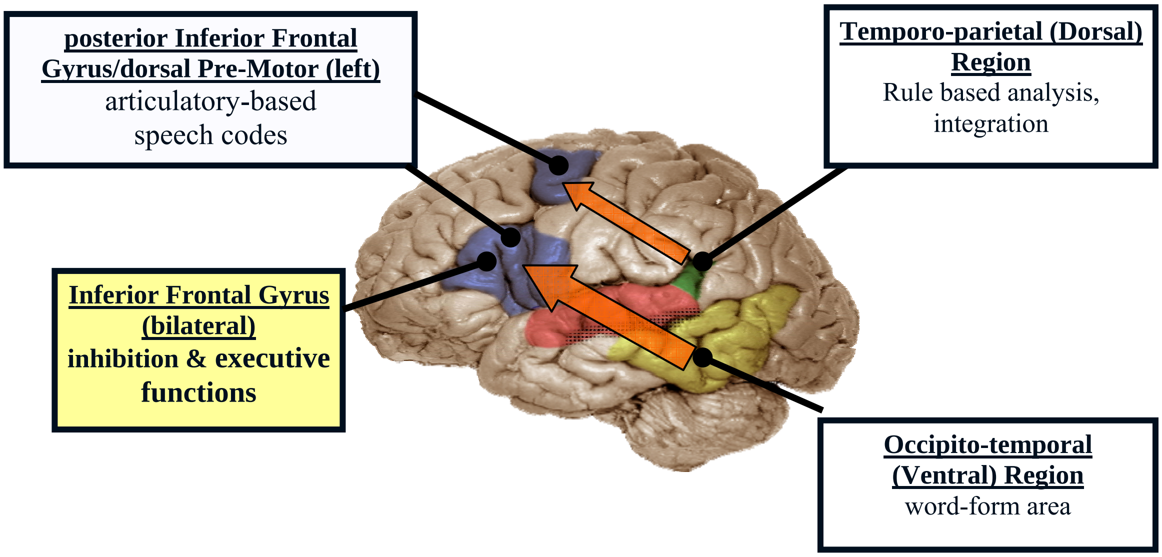

Figure 1-1. Neurological Underpinnings of Reading

CHAPTER 2
METHODS

Participants

A total of 19 children between the ages of 8 and 14-years-old participated in this study: 11 diagnosed with reading disability (RD) and 8 with no diagnosis of a RD (normal control group). The majority of participants were Caucasian. Within the RD group, 8 (72.2%) were Caucasian and 3 (27.3%) were African American. Similarly, within the control group, 6 (75%) were Caucasian, 1 (12.5%) was Hispanic, and 1 (12.5%) was African American. Participants were excluded if their intellectual functioning was suggestive of mental retardation (FSIQ scores less than 70 on the Wechsler Intelligence Scale for Children – Third Edition, WISC-III, or the Wechsler Abbreviated Scale of Intelligence, WASI), if they had a prior head injury, or history of neurological condition (e.g. seizure disorder).

The RD group was recruited through flyers that were posted within the institution or at several local elementary schools. Additionally, children with RD were referred from ongoing studies within the University of Florida's Clinical and Health Psychology Program, Pediatric Neurology Department, and the Multi-Disciplinary Diagnostic and Training Program at the University of Florida. All children had previously been diagnosed with RD by a licensed psychologist using the discrepancy method (1 SD difference between IQ and achievement). Diagnosis was confirmed using the child's Individual Education Program (IEP) and psychoeducational testing reports that were obtained by the Principal Investigator. Three children were excluded because of comorbid learning disabilities or auditory processing impairments. Children were not excluded from the study if they had ever received a diagnosis of Attention Deficit/Hyperactivity Disorder from a psychologist or pediatrician, as long they were currently taking psychostimulant medication in order to treat this disorder. Given the high rates of comorbidity of RD and ADHD (15% to 40%) it would have been extremely difficult to obtain an adequate sample size using these exclusion criteria. Furthermore, the inclusion of ADHD as a comorbidity enhances the generalizability of this sample (Gilger, Pennington, & DeFries,1992; Shaywitz, Fletcher, & Shaywitz, 1995; Willcutt & Pennington, 2000).

Children within the control group were recruited via flyers posted within the institution, local grocery stores, and at local elementary schools. The absence of diagnosis of RD and ADHD was confirmed by parent-report via a telephone screen prior to the testing session. Children were excluded if they were unable to complete any of the neuropsychological test measures (no children were excluded).

Procedures

Several domains of reading and reading comprehension were evaluated in the current study. All study participants completed the Word Attack, Letter Word Identification, and Passage Comprehension subtests from the Woodcock Johnson Tests of Achievement-Third Edition (WJ-III; Woodcock, McGrew, and Mather, 2001). Additionally, the Gray Oral Reading Tests-Fourth Edition (GORT-IV; Weiderhold & Bryant, 2001) was used to assess the rate, accuracy, fluency, and comprehension of reading ability. Raw scores from the WJ-III subtests and the GORT-IV were transformed into age-and gender-adjusted standardized scores.

WJ-III subtests yield standardized scores, with a scale mean of 100 and a standard deviation of $\pm$ 15, such that scores below 85 reflect reading impairment. The Word Attack subtest is a measure of pseudo-word reading that assesses phonological awareness. The Letter Word Identification subtest measures the ability to decode relatively high frequency real words. The Passage Comprehension subtest is a measure of covert reading comprehension.

The GORT-IV yields four scaled scores: Rate, Accuracy, Fluency, and Comprehension, and one standardized score: Oral Reading Quotient. These scaled scores have a scale mean of 10 and a standard deviation of ±3, such that scores below 7 reflect reading impairment, and the standardized score has a mean of 100 and a standard deviation of ± 15. The Rate score represents the amount of time taken by a participant to read a story. The Accuracy score represents the ability to pronounce each word in the story correctly. The Fluency score is the participant's Rate and Accuracy combined, and the Comprehension score measure the appropriateness of the participant's responses to questions about the content of each story read. Finally, the Oral Reading Quotient score is a combination the Fluency and Comprehension scores.

The current study assessed several domains of executive functions include: verbal working memory, inhibition, shifting, and attentional control/switching. Working memory was assessed using the Numbers subtest from the Children's Memory Scale (CMS; Cohen, 1997), which is essentially a Digit Span task with a forward and backward component. These scores were combined to yield a Numbers Total Scaled score with a mean of 10 and a standard deviation of ± 3. Additionally, the Numbers Forward and Numbers Backward raw scores were transformed into Scaled scores, as the Numbers Forward task is a more of a measure of attention and short-term memory, and the Numbers Backward is more taxing on the executive control aspects of verbal working memory ability as there is the component of manipulation that must be utilized in order to successfully complete the task (Lezak, 1995).

The ability to inhibit prepotent responses was assessed using the Inhibit Scaled score Delis Kaplan – Executive Function System (D-KEFS; Delis, Kramer, & Kaplan, 2001) Color-Word Interference subtest. This subtest is similar to the traditional Stroop Color-word test, but involves an additional task of switching between the classic stroop paradigm and normal word reading. Therefore, the domain of shifting was also assessed using the Switching score. All scores yielded from this subtest are scaled scores, with a mean of 10 and a standard deviation of ± 3.

The ability to shift set was also assessed using the Wisconsin Card Sorting Task-64 computerized version (WCST-64; Heaton, 1981). Although this measure yields several scores, only the Perseverative error score was used in the current study, and this score is most correlated with the ability to shift set. The scores yielded are T-scores with a mean of 50 and a standard deviation of $\pm$ 10.

Two subtests from the Test of Everyday Attention for Children (TEA-Ch; Manly, Robertson, Anderson, & Nimmo-Smith, 1999) were used to assess attentional control and switching. The Creature Counting and Opposite Worlds subtests scaled scores were combined to create a composite score to represent the ability to switch cognitive set and inhibit incorrect responses. Specifically, for each participant, scaled scores from the two attentional control and switching tasks were summed and divided by two, yielding a single composite attentional control and switching Scaled score. The creation of a composite score for this domain was performed in order to accomplish data reduction and thus reduce the number of variables to protect statistical power.

Cut-off scores of one or more standard deviation below the mean were used to qualitatively determine impairment in a domain. For instance, for Scaled Scores with a mean of 10 and a standard deviation of 3, a score of 7 or below represents impairment in that domain (Lezak, 2004).

CHAPTER 3
RESULTS

Table 1 presents means (and standard deviations) for each group of participants for chronological age, Full Scale IQ (FSIQ), Performance IQ (PIQ), and Verbal IQ (VIQ). A t-test revealed that the groups were comparable in terms of age at the time of assessment ($t(2) = -.234$, $p = .817$). Chi square analysis similarly revealed that the two groups were comparable in terms of ethnicity, with approximately 75% Caucasian in both groups (X^2 (2, N = 19) = 43.50, p = 0.00). T-tests were also conducted on the IQ scales (FSIQ, PIQ, VIQ). Groups were comparable across all measures (FSIQ ($t(2) = 1.03$, $p = .319$), PIQ ($t(2) = -.551$, $p = .589$, and VIQ ($t(2) = 1.78$, $p = .095$). See Table 3-1.

Reading Ability Measures

In order to better characterize our samples, we used a MANOVA to compare groups on the dependent measures for each of the reading domains. The dependent measures (DVs) were the Standard Scores for real and pseudo-word reading, covert passage comprehension, and the rate, accuracy, and comprehension for passage reading. Additionally, a standard score was used to represent overall oral reading ability. Table 2 illustrates group means and standard deviations for the reading measures. The overall multiple analysis of variance found significant main effects for group ($F[7,10] = 7.87$, $p < .01$, $\eta^2=.846$). This effect size suggests a large effect of group (Field, 2005). Follow-up univariate ANOVAs were conducted to examine the location of the significant effect. Significant effects of pseudo-word reading ($F[1,17] = 5.64$, $p < .05$, $\eta^2=.261$), rate of passage reading ($F[1,17] = 15.11$, $p < .01$, $\eta^2=.486$), accuracy of passage reading ($F[1,17] = 26.82$, $p \leq .001$, $\eta^2=.626$), fluency of passage reading ($F[1,17] = 20.30$, $p \leq .001$, $\eta^2=.559$), comprehension of passage reading ($F[1,17] = 8.56$, $p < .05$, $\eta^2=.349$), and overall oral reading ability ($F[1,17] = 17.40$, $p < .01$, $\eta^2=.521$) were found between groups, with the RD group performing worse on all tasks with significant differences. Although the RD group performed worse on most of the reading ability measures compared to the control group, the group was in the impaired range (-1 SD) for only rate, accuracy, fluency, and overall oral reading ability measures. See Table 3-2.

Executive Function Measures

Initial evaluations of the data suggested that all measures were univariate normal (i.e., all dependent variables had skewness and kurtosis between -1 and 1.) The *Box-M* test for the homogeneity of variance-covariance matrices across design cells produced a non-significant result and the Levene's test found that the assumption of homogeneity of variance could be supported for the main effect of group. Residual correlations between the DVs were only reaching relatively high levels for the two D-KEFS variables (.832), suggesting possible non-independence of these DVs. Otherwise, it can be assumed that the DVs represent unique information relative to one another.

We used a MANOVA to compare groups on the dependent measures for each factor of executive functions. Scaled scores were considered to be the dependent measure for the domains of verbal working memory, inhibition, and shifting; and a T-Score was used as the dependent measure of set-shifting. A composite of two Scaled scores was used as the dependent measure for the domain of attentional control and switching. Table 2 illustrates group means and standard deviations for the executive functions tasks. The overall multiple analysis of variance found a significant main effect for group ($F[1,17] = 17.40$, $p < .01$, $\eta^2=.521$). We conducted follow-up univariate ANOVAs, separately for each DV, to examine the location of the significant effect. Significant effects of verbal working memory ($F[1,17] = 11.32$, $p < .01$, $\eta^2=.400$), inhibition ($F[1,17] = 7.17$, $p < .05$, $\eta^2=.297$), shifting for the D-KEFS Switching variable ($F[1,17] = 10.15$, $p < .01$, $\eta^2=.374$), and attentional control and switching ($F[1,17] = 7.56$, $p < .05$, $\eta^2=.308$) were found between groups, with the RD group performing worse on all significant variables. There was no significant difference between groups for the domain of shifting as measured by the WCST-64. Additionally, in order to control for inflated family-wise error, the alpha level of $p<.05$ was adjusted to reflect the number o DVs used in the MANOVA, yielding an alpha level of $p<.025$. All variables of significance remain at the significant level when adjusting for family-wise error. In order to determine if group differences in the Numbers Forward and Numbers Backwards tasks existed, an independent samples T-test was conducted. The RD group performed worse for both Forward and Backward ($t(17) = 2.22$, $p = .041$; $t(17) = 3.31$, $p = .004$). Qualitatively, the RD group performed in the impaired range (- SD) in the domains of inhibition and attentional control and switching. See Table 3-3.

Parent-Report Behavioral Measure

A MONOVA of the three BRIEF scales of interest (Inhibit, Shift, and Working Memory) indicated that the overall model is significant ($F[1,17] = 3.28$, $p < .05$, $\eta^2=.396$). Follow-up univariate analyses of variances indicated that children with RD were rated as having significantly higher scale elevations (indicative of higher problem levels) on the Shift scale ($F[1,17] = 7.78$, $p < .05$, $\eta^2=.314$). Qualitatively (using recommended clinical cut-off values), children with RD were noted to have been rated within the clinical range only on the Working Memory scale. Table 4 presents the group means for the BRIEF scales. See Table 3-4.

Table 3-1 Group Means and Standard Deviations for Age and IQ

	RD (*N* = 11)	Control (*N* = 8)	p-value
Chronological Age (CA)	11.17 (1.83)	10.91 (2.75)	0.817
Full Scale IQ (FSIQ)	102.64 (12.32)	109.38 (16.34)	0.319
Performance IQ (PIQ)	109.70 (12.45)	106.13 (15.13)	0.589
Verbal IQ (VIQ)	97.89 (14.07)	111.25 (16.83)	0.095

Table 3-2 Means (and Standard Deviations) on Reading Measures: RD vs. Control

Reading Task Domain	RD *(N=11)*	Control *(N=8)*	p-value	Effect size
Pseudo-word Reading				
WJ-III Tests of Achievement (Word Attack Scaled score)	96.27 (10.00)	105.00 (6.40)	.030	.261
Real Word Reading				
WJ-III Tests of Achievement (Word Identification Scaled score)	89.00 (23.28)	108.00 (7.67)	.055	.211
Covert Passage Comprehension				
WJ-III Tests of Achievement (Passage Comprehension)	92.90 (9.90)	101.14 (14.73)	.228	.089
Reading Rate				
GORT-IV Rate Scaled score	5.64 (3.04)	10.86 (2.27)	.001	.486
Reading Accuracy				
GORT-IV Accuracy Scaled score	6.73 (2.28)	11.57 (1.13)	≤.001	.626
Reading Fluency				
GORT-IV Fluency Scaled score	4.82 (3.55)	11.29 (1.60)	≤.001	.559
Reading Comprehension				
GORT-IV Comprehension Scaled score	8.55 (2.50)	11.43 (.79)	.010	.349
Overall Oral Reading Ability				
GORT-IV Oral Reading Quotient	80.09 (16.93)	108.14 (6.18)	.001	.521

Table 3-3 Means (and Standard Deviations) on Executive Functions Measures: RD vs. Control

Executive Function Domain	RD *(N=11)*	Control *(N=8)*	p-value	Effect size
Verbal Working Memory				
Numbers Scaled score from CMS	8.27 (1.74)	11.25 (2.21)	.004	.400
Numbers Forward Scaled score	8.13 (2.40)	10.13 (.641)	.041	.103
Numbers Backward Scaled score	7.60 (2.66)	11.38 (2.07)	.003	.416
Inhibition				
D-KEFS Interference subtest (Inhibition Scaled score)	6.64 (2.66)	9.38 (1.30)	.016	.300
Shift				
D-KEFS Interference subtest (Switching Scaled score)	7.35 (3.04)	11.00 (1.20)	.005	.374
WCST-64 Perseverations T-Score	55.91 (14.75)	56.63 (21.43)	.932	.000
Attentional Control and Switching				
TEA-Ch Attentional Control composite Scaled score	4.95 (3.45)	8.89 (2.42)	.014	.308

Table 3-4 Means (and Standard Deviations) on three scales of the Behavioral Rating Index of Executive Functions (BRIEF) Parent-report

Index Scale	RD *(N=11)*	Control *(N=8)*	p-value	Effect size
Inhibit	58.82 (11.05)	49.5 (12.90)	.109	.144
Shift	60.00 (13.44)	44.5 (9.47)	.013	.314
Working Memory	65.00 (12.11)	59.13 (16.39)	.380	.046

CHAPTER 4
DISCUSSION

The primary goals of the current study were to characterize the profile of executive functions (EF) performance in children with Reading Disability (RD) and to investigate if this childhood neurodevelopmental disorder could be differentiated from a normal control group. The results suggest that the executive functions profile for this population reflect impairment as hypothesized. Consistent with our predictions, the RD group exhibited deficits on the both the neuropsychological measures of EF and on parent ratings of EF behaviors. Qualitative examination of the RD group's neuropsychological profile revealed impaired performance (1 SD below the mean) in the domains of inhibition and attentional control/switching. The RD group also was rated in the clinically significant range in the domain of working memory. Moreover, the RD group performed significantly worse than the control group in the domains of verbal working memory, inhibition, shifting, and attentional control and switching. Furthermore, the RD was rated has having more behavioral elevations than the control group in the shifting domain.

Working Memory

It was hypothesized that the domain of verbal working memory would be a critical component of executive functions in distinguishing RD from the control group. This prediction was based on prior studies, as well as the proposed role that verbal working memory plays in the mediation of lower-level processors (e.g., phonological processing) in a model of the linguistic system (Alexander & Slinger, 2004). Specifically, digit span forward is frequently used as a measure of the phonological loop of Baddeley's (1992) model for working memory, as this task relies on the phonological loop with little reliance on the central executive system. The 'backward' component of this task requires resources of the central executive system as the manipulation of information is needed (Lezak, 2004). Thus, current study results indicated that the RD group performed significantly worse than controls in the attentional aspects of this task as well as the executive control component. These findings are consistent with past research (Wilcutt, et al., 2001; Lezak, 1995; Reiter, Tucha, & Lange, 2005; Jeffries & Everatt, 2004; Kibby, Marks, & Morgan, 2004; Swanson, 2003; Poblano, 2000; Jong, 1998) and support the notion that the neural substrates underlying both verbal working memory and phonological processing appear to be located in overlapping brain regions in the left hemisphere (Shaywitz, 2005). However, this notion would need to be confirmed with functional neuroimaging.

Inhibition

As hypothesized, the RD group performed significantly worse on a neuropsychological measures of inhibition compared to the control group. The ability to inhibit prepotent responses was assessed using the score from the Interference trial from the D-KEFS Color-Word Interference test. Of note, the RD group did not differ from the control group in the total time taken to read the words for the Word trial, nor did they differ in their ability to rapidly name colors. Therefore, the RD group's difficulty on the Interference trial cannot be attributed to differences in reading rate or in color naming, and the statistical difference between groups is attributed to the inability to adequately inhibit the natural response of word reading.

Several studies using factor analyses and regression models have demonstrated that response inhibition tasks are implicitly involved in measures of the central executive system (Rucklidge and Tannock, 2002; Purvis and Tanock, 2000). These findings support the notion that inhibition and working memory are closely related, as proposed by Baddeley's model of working memory (Baddeley, 2002). For instance, working memory maintenance of task-set and items and the selection and manipulation of information in working memory requires cognitive inhibition (Aron, Robbins, & Poldrack, 2004; Duncan & Owen, 2000). Furthermore, a close link has been found between reading and speeded inhibition measures, (Purvis and Tanock, 2000). These findings are also supported by the common neural substrates shared by both inhibition and phonological processing, distinctively in the inferior frontal gyrus (Aron, Robbins, & Poldrack, 2004; Shaywitz & Shaywitz, 2005). Taken together, these findings suggest that inhibition is a necessary component for successful reading.

Shifting

Two measures were used to assess the shifting domain of executive functioning in this study. The Switching score from the D-KEFS Color-Word Interference test was found to significantly differentiate the groups, with the RD group performing worse. However, the WCST-64 failed to detect group differences. There are several potential explanations for these divergent findings. First, the Switching score from the D-KEFS Color-Word Interference test requires one to not only inhibit their prepotent response (as described above), but also to shift sets and, at times, read the word regardless of the ink color it is printed in. Specifically, when a word on the page has a box surrounding it, the correct response is to read the word and not name the ink color, but when there is no box surrounding the text, the correct response is to name the color of ink, not read the word. Successful completion of this task not only requires inhibition, but also the ability to shift between rules. There have been no studies that have used this scoring component of the D-KEFS Color-Word Interference subtest in the RD population. Given the reported deficits in inhibition and the role that inhibition plays in set-shifting in this task, it follows that children with RD would perform poorly (Asbjørnsen & Bryden, 1998; Keshner & Morton, 1990).

The WCST-64 was also used to assess set-shifting. Statistically significant differences were not found between groups for both perseverative and non-perseverative errors. First, this task does not have a time demand, and the participant may take as long as necessary to decide which card is the most appropriate match. The literature suggests that children with RD may have a marked deficit in tasks that require speeded processing (van der Sluis**,** de Jong, & van der Leij, 2004; Tallal, Allard, Miller, & Curtiss, 1997). Therefore, time demands for a task may be necessary in order for potential impairment in the domain to be observable. Furthermore, the WCST-64 may not be a specific enough task in detecting frontal lobe pathology explicitly in the shifting domain. For instance, there is a lack of association between WCST-64 errors and specific cognitive and neural processes (Barcelo & Knight, 2002).

Attentional Control and Switching

In support of our hypothesis, there was a significant group difference found in the domain of attentional control and switching, with the RD group performing significantly worse than the control group. One way to conceptualize the attentional control and switching subtests of the TEA-Ch is as tasks that combine the executive function components of inhibition and set-shifting. Although this limits our ability to draw definitive conclusions regarding the specific components of EF that differ between RD and controls, we can infer that both aspects of this domain are impaired when considered relative to the findings in the current study. This suggests that children with RD do have a generalized impairment in set-shifting when this skill is used in conjunction with other cognitive skills such as inhibition and attentional control.

Many studies have investigated components of attention in children with RD and yielded equivocal results (Helland & Asbjørnsen, 2000; Pennington, 2006; Willcutt & Pennington, 2000; Wilcutt, Pennington Olsen, Chabildas, & Hulslander, 2005), in part because the rate of comorbidity between RD and Attention Deficit/Hyperactivity Disorder (ADHD) has been reported to be as high as 45% (Purvis & Tannock, 2000; Wilcutt, Pennington Olsen, Chhabildas, & Hulslander, 2005). The conventional methods of separating RD caused by deficits in decoding skills from poor reading caused by attention problems associated with ADHD have yielded equivocal results (Aron, Robbins, Poldrack, 2004). There are several hypotheses proposed to explain the high comorbidity rates, including phenotypic sources, in which the observable characteristics are similar (Wilcutt *et al*., 2001), genetic causes (Pennington, Bennet, McAteer, & Roberts, 1996; Wilcutt *et al*., 2002); and hereditary causes (Wilcutt *et al*., 2002). In particular, an extensive twin study found that approximately 95% of the phenotypic covariance between RD and symptoms of inattention was attributable to common genetic influences. Furthermore, 21% of the phenotypic overlap between RD and hyperactive and impulsive behaviors was due to common genetic factors (Wilcutt *et al*., 2002). These findings suggest that RD and ADHD do, in fact, share potential genetic overlap (Pennington, 2006).

The investigation of reading problems and EF impairment associated with both RD and ADHD remains an important avenue of research because of the potential implications in the ability differentially diagnosis and treat RD and ADHD. It is imperative to understand the underlying deficits in order to better conceptualize and treat a disorder.

Parent-Rating of Executive Functions

Neuropsychological testing alone may not fully capture the EF profile in this population. Therefore, three scales from the BRIEF Parent-report (Inhibit, Shift, and Working Memory) were compared between groups. Contrary to our hypothesis of group differences across these scales, only the Shift scale was significantly different between groups, with the RD group being rated as having more significant problems. Furthermore, only the Working Memory scale for the RD group was reported in the clinically significant range ($T \geq 65$). All other scales were within ‘normal limits’ for both groups, suggesting that as a group, the RD group is not being reported by their parents to be displaying EF difficulties. These findings are somewhat contradictory to previous findings, in which group differences were found between RD and controls on the Working Memory scale, but not on the Inhibit or Shift scales (Gioia, Isquith, Kenworthy, & Barton, 2002). However, Gioia *et al*. (2002) failed to find the RD in the clinically significant range for the three scales of interest in this study, which is consistent with our findings.

Sample characteristics and limited power may help explain our failure to detect significant group differences for all three scales as hypothesized. If behavioral observations reflect executive function impairment as detected by neuropsychological measures, the RD group would be expected to have been rated has having more problems in these domains than our sample exhibited. The performance of the RD group in the current study suggests that these children may represent the milder end of the disorder’s spectrum.

Additionally, the relatively small sample size of the current study may have impacted our ability to detect statistically significant group differences. Although the RD group received higher (more problematic) ratings than the control group, a larger sample may potentially demonstrate significant group differences on these scales, although the current study’s effect sizes are small. Few studies of this population have included parent-ratings in addition to a neuropsychological battery, and it is difficult to determine the overall pattern of behaviorally manifested executive function problems.

Limitations and Strengths of Current Study

The implications of our findings are tempered by the limitations of the current study. Due to the nature of a pilot study our sample size, and therefore power, was relatively small.

It is important to note, however, that the significant differences found between groups on the neuropsychological measures of executive functions yielded medium effect sizes (Field, 2004), suggesting that the group differences found in the current study would be replicable with a larger sample. Also, neuropsychological measures inherently assess multiple domains of EF, creating difficulty in determining impairment in specific domains of EF. This limitation highlights the need for future test development to improve the utility of neuropsychological measures that focus on one component of EF.

Additionally, children with RD were compared with a group of controls that were not age- or reading age-matched. Snowling (1987) has emphasized that the value of considering studies without reading age-matched controls is limited, as conclusion drawn with regard to reading ability and executive functioning should be taken conservatively. The lack of phonological measures that specifically assess lower-level phonological processing limit our ability to more fully relate the proposed model of linguistic impairment in this population and executive functions. In order to explore the relationship between lower-level processes, such as phonological awareness, and the role executive functions may play in the mediation of reading ability, a range of assessment measures must be employed. Furthermore, the IFG is specifically involved in the phonological awareness and articulatory recoding aspects of reading, and therefore, it is difficult to draw conclusions regarding these abilities and the executive functions associated with activation of the brain region without more sensitive reading measures, and ultimately, without functional neuroimaging.

Finally, the RD group included children with comorbid ADHD (n=5, 45% of RD sample). All participants with comorbid ADHD and RD were being treated pharmacologically, which has been shown to alleviate EF impairment in ADHD. However, this could pose a potential limitation to the current study. Although it is not feasible for post-hoc examination of the RD group's performance because of sample size limitations, qualitative performance for the five participants with only RD (i.e., no comorbid ADHD) was examined, revealing impairment for three participants in the working memory domain, four participants demonstrated impairment in the inhibition domain, four participants demonstrated impairment in the switching domain, and four participants demonstrated impairment in the attentional control domain. Additionally, on the parent-report measure of EF, two participants were rated in the clinically significant range for the Inhibit index, three participants were rated in the clinically significant range for the Shift index, and 3 participants were rated in the clinically significant range for the Working Memory index. This impairment profile suggests that children with RD without ADHD exhibit EF impairment and the comorbidity of ADHD is not a necessary condition for EF impairment to exist in this population.

There are a number of strengths to the study. For instance, few studies of children with RD have utilized a comprehensive neuropsychological test battery that focuses on the related domains of executive functions. Inhibition, working memory, and set-shifting have similar underlying cognitive and neural substrates, and few studies of this population have simultaneously investigated these domains in comparison to normal controls. In order to tease apart the specific fundamental executive function impairments within this population, systematic examinations of this nature must be performed. Executive functioning may affect not only the present cognitive functioning, but also the integrity of future cognitive functions and the effectiveness of remediation (Reiter, Tucha, & Lange, 2005).

Future Directions

Using a multidimensional model of executive functions and parent ratings of behavior, the current pilot study successfully describes an expected executive function profile for RD, as well as illustrates how the pattern of RD performance differs from a control group consisting of non-impaired readers. The next step is to examine a pure sample of children with RD only, and then look at a sample with comorbid ADHD, as clinical group comparisons (i.e., RD, RD+ADHD, and control) are warranted given the similar executive dysfunction pattern found in the ADHD population (Wilcutt *et al*., 2002; Wilcutt, Pennington, Olsen, Chhabildas, & Hulslander, 2005). Furthermore, the inclusion of more sensitive reading measures to the test battery would also be a beneficial addition. The relationship between the fundamental aspects of reading ability and executive functions could be addressed. Moreover, the utilization of functional neuroimaging (e.g., fMRI) would enable researchers to definitively investigate the relationships between EF and RD. Finally, the role that executive dysfunction plays in response to remediation is an important subject for further research. Previous research suggests that the possible differences in executive function may differentiate between children who will be more likely to respond to intervention and those who do not respond as well (Shaywitz *et al*., 2003). If such deficits could be detected early, potentially at the elementary school level, remedial treatment could be tailored to specific subgroups of reading impaired individuals.

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BIOGRAPHICAL SKETCH

Sarah McCann was born in Corvallis, OR, the younger of two children of Martha and Joseph McCann. She earned a Bachelor of Science degree in psychology with a concentration in biology at the University of Tampa. Sarah entered the Clinical and Health Psychology program at the University of Florida in 2005. During her study at UF, she has worked as a research assistant in a pediatric neuropsychology lab and a stroke rehabilitation center. Sarah's mentor is Shelley C. Heaton, Ph.D., and her interests include childhood neurodevelopmental disorders such as learning disabilities and attention deficit hyperactivity disorder. She plans to work in a clinical research setting after earning her doctoral degree in clinical psychology.