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Executive Dysfunction Among Children With Reading Comprehension Deficits

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Abstract

Emerging research supports the contribution of executive function (EF) to reading comprehension; however, a unique pattern has not been established for children who demonstrate comprehension difficulties despite average word recognition ability (specific reading comprehension deficit; S-RCD). To identify particular EF components on which children with S-RCD struggle, a range of EF skills was compared among 86 children, ages 10 to 14, grouped by word reading and comprehension abilities: 24 average readers, 44 with word recognition deficits (WRD), and 18 S-RCD. An exploratory principal components analysis of EF tests identified three latent factors, used in subsequent group comparisons: Planning/Spatial Working Memory, Verbal Working Memory, and Response Inhibition. The WRD group exhibited deficits (relative to controls) on Verbal Working Memory and Inhibition factors; S-RCD children performed more poorly than controls on the Planning factor. Further analyses suggested the WRD group's poor performance on EF factors was a by-product of core deficits linked to WRD (after controlling for phonological processing, this group no longer showed EF deficits). In contrast, the S-RCD group's poor performance on the planning component remained significant after controlling for phonological processing. Findings suggest reading comprehension difficulties are linked to executive dysfunction; in particular, poor strategic planning/organizing may lead to reading comprehension problems.

Keywords

reading; ADHD; dyslexia; comprehension; executive function; working memory

Introduction

Deficits in reading comprehension can have detrimental effects on overall school achievement, access to community resources, and occupational attainment. Reading comprehension deficits (RCD) in children have been linked to impairments in decoding and recognizing words (Lyon, 1995; Torgesen, 2000), fluency/word reading speed (LaBerge & Samuels, 1974; Perfetti & Hogaboam, 1975; Perfetti, Marron, & Foltz, 1996), oral language skills (Gough & Tunmer, 1986), and, more recently, executive function (Cutting, Materek, Cole, Levine, & Mahone, 2009).

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Deficits in word recognition and oral language skills have been extensively studied and have been well established as negatively affecting reading comprehension (Shankweiler et al., 1999; Torgesen, 2000). Significantly less research has focused on *other* potential contributors to reading comprehension deficits, particularly in those children whose word recognition skills are solid but who nonetheless experience comprehension difficulties (specific reading comprehension deficit; S-RCD). In fact, a significant number of children are poor comprehenders but nevertheless attain scores within the normal range on word recognition. It is estimated that approximately 10% to 25% of poor readers, or about 3% of the school-age population, exhibit this type of reading profile, particularly as they get older (e.g., Aaron, Joshi, & Williams, 1999; Catts, Adlof, & Weismer, 2006; Kollins et al., 2006; Leach, Scarborough, & Rescorla, 2003; Shankweiler et al., 1999), although some have reported that 10% of all children fit the S-RCD profile (Nation, Clarke, Marshall, & Durand, 2004). Thus, basic word recognition deficit (WRD) models, which propose that poor phonological processing is a core weakness in WRD, do not appear to explain the deficits found in students with S-RCD.

In an effort to understand more about the various skills that contribute to reading comprehension, particularly beyond those that are well established (i.e., word recognition and oral language; Gough & Tunmer, 1986), researchers have begun to examine the role of various executive function skills in reading comprehension (Cutting et al., 2009; Sesma, Mahone, Levine, Eason, & Cutting, 2009). Executive function (EF) refers to a set of cognitive processes utilized in the management of goal-directed behaviors and in the development and implementation of an approach to completing tasks that have not been habitually performed (Mahone et al., 2002). It is a multidimensional construct, separable from (but dependent on) core “ingredient” skills such as vocabulary, visuospatial skills, and intelligence. EF is central to performance and is critical in remediation of skill deficits (Denckla, 1996). As a multidimensional construct, executive functioning has been conceptualized to include such core processes as *response inhibition* (Friedman et al., 2006; Miyake et al., 2000; Willcutt, Sonuga-Barke, Nigg, & Sergeant, 2008), *planning* (Bauman & Kemper, 1994; Brookshire, Levin, Song, & Zhang, 2004; H. S. Levin et al., 1996), and *working memory* (Brookshire et al., 2004; Willcutt et al., 2001, 2008). While researchers describe a number of subcomponents of the EF construct, there is a growing consensus that working memory and inhibition comprise two core elements of the executive function construct (Pennington & Ozonoff, 1996; Verte, Geurts, Roeyers, Oosterlaan, & Sergeant, 2006), and that they may be dissociable in children (Mahone et al., 2005; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005; Ozonoff & Jensen, 1999). Verbal working memory is especially critical to classroom learning (Kibby et al., 2004) and has been linked to reading comprehension, both in normal, highly experienced readers (Swanson & Alexander, 1997) and in those with reading difficulties (Sesma et al., 2009).

In general, the reading comprehension literature has linked the areas of working memory (Reiter, Tucha, & Lange, 2005; Swanson, 2003), planning/organization (B. E. Levin, 1990; Chiarenza, 1990; Sesma et al., 2009), and inhibition (Savage, Cornish, Manly, & Hollis, 2006) to reading comprehension. Nonetheless, it should be pointed out that while the literature on working memory and reading comprehension is extensive, fewer studies have investigated the connection between reading comprehension and planning/organization and inhibition; furthermore, distinctions between reader profiles (e.g., WRD and S-RCD) have not always been examined.

It also is important to note that although there is a comprehensive body of literature examining the links between working memory and reading comprehension, the exact mechanism, particularly in children with poor reading skills, is still being explored. To this end, some researchers have proposed that executive functions may be a major component of working memory, rather than working memory being a component of executive functions (Baddeley &

Hitch, 1974; Gathercole & Baddeley, 1993; Lui & Tannock, 2007). It has also been proposed that verbal working memory specifically includes phonological processes (a phonological storage and a phonological loop) and executive functions for inhibiting or switching during reading or writing (Berninger, Abbott, Vermeulen, & Fulton, 2006). In fact, it is thought that it is the phonological core processes of working memory, versus the executive components, that are related to problems in decoding, fluency, and spelling commonly found in individuals with WRD (e.g., Lefly & Pennington, 1991).

While phonological processes clearly have a role in working memory, other aspects of executive function, notably the planning and organization components, have been shown to differentially support reading comprehension while being less necessary for word recognition (Sesma et al., 2009). Moreover, a recent study that included typically developing children, children with WRD, and those with S-RCD also revealed that there appear to be prominent deficits in executive function skills associated with reading comprehension (Cutting et al., 2009), specifically in planning and organization skills (excess moves on a Tower of London task). Thus, recent work suggests that specific aspects of executive function in particular may be linked to reading comprehension.

In addition to its involvement in reading disorder processes, executive dysfunction is routinely described in samples of individuals with Attention-Deficit/Hyperactivity Disorder (ADHD). In fact, a recent meta-analysis revealed that a significant difference in EF deficits was observed between groups with and without ADHD in 64% of the total comparisons, indicating a medium effect size (Willcutt et al., 2008). The most consistent group differences and largest effect sizes were noted specifically on measures of motor response inhibition, working memory, vigilance, and planning, which are cognitive skills that would seemingly be necessary for reading comprehension. In addition, it has been suggested that children with ADHD *without* word reading difficulties have deficits in reading comprehension as a result of their ADHD-related executive function deficits (Brock & Knapp, 1996; McInnes, Humphries, Hogg-Johnson, & Tannock, 2003). Considering the comorbidity of reading disorders in children diagnosed with ADHD (Dykman & Ackerman, 1991; Gilger, Pennington, & DeFries, 1992; Shaywitz et al., 1995; Willcutt & Pennington, 2000), it is possible that weaknesses in executive functioning may contribute to poor comprehension abilities in children with and without ADHD diagnoses.

The goal of the present study was to examine a wide range of executive function skills among three groups of children: (a) those with WRD; (b) those with S-RCD, namely, who do *not* have concomitant deficits in word recognition; and (c) typically developing children. The purpose of examining a wide range of executive function skills was to determine the patterns of executive dysfunction that may be unique to reading difficulty; especially important was the inclusion of distinct reader profiles as well as a comprehensive battery of executive function measures, as previous studies have been limited in terms of which aspects of executive function were studied and very few have included S-RCD and WRD groups. For the WRD group we were interested in identifying if any executive function deficits were observed, and if so, were they in fact a by-product of the core deficits linked to basic word recognition deficits (i.e., phonological processing). Since most children with WRD also have reading comprehension deficits, it was hypothesized that a certain level of executive dysfunction (relative to controls) *could* be observed across skill areas in this group; however, it was hypothesized that the executive deficits observed may be different in nature to those seen in S-RCD. More specifically, we hypothesized that children with WRD would show particular deficits in working memory, possibly related to their basic weaknesses in phonological processing, and that these weaknesses may no longer be present when phonological processing was controlled for. In contrast, it was hypothesized that children with S-RCD would manifest deficits in components of executive function shown previously to be more distinctively related to reading comprehension, namely, strategic planning/organization (Cutting et al., 2009), and that these would be present regardless of whether phonological processing was accounted for. An open question was the degree to which children with S-RCD would show deficits in *other* areas of executive function in addition to the planning and organization weaknesses observed in our previous study of S-RCD (Cutting et al., 2009). It should be noted that because the present study included a comprehensive battery of measures, we could address the important issue of the extent of executive function deficits present in S-RCD. Our previous study, with its limited battery of executive function measures, was not able to address this issue.

Method

Participants

Children between the ages of 10 and 14 years were recruited to participate in a study of reading. Study recruitment flyers were mailed to directors of learning disability organizations and clinics and posted in the community. Study participation was limited to this age group for two reasons. First, normative data for these ages were available for nearly all instruments in the assessment battery, allowing all participants to be assessed with the same set of tests. Second, the youngest study participants were in the fourth grade. Prior to third grade, reading instruction emphasizes word decoding or "learning to read," whereas the emphasis shifts to reading comprehension or "reading to learn" in late elementary school, and children are moving from decoding individual words to automatic, efficient word identification (Yovanoff, Duesbery, Alonzo, & Tindal, 2005).

Three participant groups were formed for the main analyses. Children were classified as having word recognition deficits if they had a score at or below the 25th percentile (standard score ≤ 90) on the *Basic Skills Cluster of the Woodcock Reading Mastery Test–Revised/Normative Update* (WRMT-R/NU), which is a composite of two subtests: *Word Identification* and *Word Attack*. Children with specific reading comprehension deficits were identified by average word recognition (i.e., WRMT-R/NU *Basic Skills Cluster* at or above the 37th percentile/standard score ≥ 95), but scores at or below the 25th percentile (standard score ≤ 90; scaled score ≤ 8) on at least two of five reading comprehension measures: *Reading Comprehension* from the *Stanford Diagnostic Reading Test, Fourth Edition* (SDRT-4); *Comprehension* from the *Gates-MacGinitie Reading Tests–Fourth Edition; Reading Comprehension* from the *Diagnostic Achievement Battery* (DAB); *Comprehension* from the *Gray Oral Reading Test–Fourth Edition* (GORT-IV); and/or *Passage Comprehension* from the WRMT-R/NU. Children in the control group were required to score at or above the 37th percentile (standard score ≥ 95) on the WRMT-R/NU *Basic Skills Cluster* as well as on the five reading comprehension measures or on four out of the five measures, with the fifth score being above the 25th percentile (standard score > 90; scaled score > 8). A variety of reading comprehension measures were used because data have shown that performance can vary based on characteristics of the test, such as passage length, question format, availability of the text during questions, and whether passages are read aloud or silently (Carlisle, 1991; Cutting & Scarborough, 2006; Keenan, Betjemann, & Olson, 2008).

Procedures

All children participating in the study were screened by an initial telephone interview, and recent psychometric testing was reviewed if available. Children were excluded from participation based on: (a) previous diagnosis of Mental Retardation (Intellectual Disability) or Pervasive Developmental Disorder, (b) known uncorrectable visual impairment, (c) documented hearing loss of 25 decibels or more in either ear, (d) history of known neurological disorder (e.g., epilepsy, cerebral palsy), (e) treatment with psychotropic medications for any psychiatric disorder other than ADHD, and (f) both Verbal Comprehension Index (VCI) and Perceptual Reasoning Index (PRI) scores below 80 or Full Scale IQ (FSIQ) above 130. Children who met criteria for ADHD, Oppositional Defiant Disorder, and/or Adjustment Disorders were included in all three groups. Children with ADHD who were being treated with medications other than stimulants were excluded from this study; children being treated with stimulant medications were asked to stop taking them the day before and the two days of testing. Children with ADHD were included in the study because of the hypothesized relation between reading comprehension deficits and executive dysfunction in children with intact word recognition skills. Children with comorbid Oppositional Defiant Disorder (ODD) were retained in the study because while research suggests that ADHD and comorbid Conduct Disorder may constitute a discrete subtype, similar findings have not been reported for ADHD with comorbid ODD (Biederman, Fara-one, & Lapey, 1992). Children with all other comorbid psychiatric disorders were excluded in order to specifically examine the neuropsychological profile associated with reading disorders (RD).

Study Measures

Screening Measures

Behavior Rating Inventory of Executive Function (BRIEF; Gioia, Isquith, Guy, & Kenworthy, 2000): The parent form of the BRIEF was used in the current study as a descriptive measure. The BRIEF is a caregiver rating of executive function skills. Scores are obtained on the following scales: *Initiate, Inhibit, Working Memory, Plan/Organize, Organization of Materials, Self-Monitor, Shift*, and *Emotional Control*. Index scores for *Metacognition, Behavioral Regulation*, and *Global Executive Composites* (GEC) are obtained. *T* scores for the GEC were examined to characterize the sample.

Hollingshead Index (Hollingshead, 1975): The four-factor index was used as a measure of socioeconomic status (SES).

Wechsler Intelligence Scale for Children, Fourth Edition (WISC-IV; Wechsler, 2003): The WISC-IV Full Scale IQ score was used to assess overall intellectual ability.

Reading Measures and Reading-Related Measures—Phonological Processing, Word Recognition, and Fluency

Comprehensive Test of Phonological Processing (CTOPP;Wagner, Torgesen, & Rashotte, 1999): A phonological processing composite comprising of the phonological awareness, phonological memory, and rapid naming subtests was used as an overall measure of phonological processing. Phonological processing has been shown to be highly related to basic reading ability.

Woodcock Reading Mastery Tests–Revised/Normative Update (WRMT-R/NU; Woodcock, 1998): Standard scores from the *Basic Skills Cluster* were used to form groups and to describe the sample. The *Basic Skills Cluster* is a composite of the *Word Identification* subtest, a measure of single-word sight reading, and *Word Attack*, which measures the ability to sound out words.

Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999): Standard scores from the *Sight Word Efficiency* (SWE) subtest were used to assess single word fluency. Fluency is measured by the number of words the participant accurately reads within 45 seconds.

Orthographic Word-Pseudohomophone Choice (OWPC; Olson, Wise, Conners, Rack, & Fulkner, 1989): The OWPC task was used to further assess fluency. Participants simultaneously view a real word and a pseudohomophone and identify the real word by pressing a corresponding button (left or right). Performance was assessed by the number of correct items.

Reading Measures—Comprehension

Stanford Diagnostic Reading Tests–Fourth Edition (SDRT-4; Karlsen & Gardner, 1995): The *Comprehension* subtest, which measures literal and inferential comprehension of textual, functional, and recreational reading material, was administered. Percentiles were used to determine grouping; stanines were used for analyses.

Gates-MacGinitie Reading Tests, Fourth Edition (MacGinitie, MacGinitie, Maria, & Dreyer, 2002): The *Comprehension* subtest was administered, which required participants to read passage of text silently and answer relevant comprehension questions. Percentiles were used to determine grouping; stanines were used for analyses.

Diagnostic Achievement Battery, Third Edition (DAB; Newcomber, 2001): The *Reading Comprehension* subtest was administered, which required participants to read passage of text and answer relevant comprehension questions. Scaled scores were used for group formation and in analyses.

Gray Oral Reading Test, Fourth Edition (GORT-IV; Wiederholt & Bryant, 2000): The GORT-IV assesses oral text reading fluency and comprehension. Participants read a paragraph orally and answer multiple choice questions; separate reading fluency and comprehension scores are provided. Scaled scores for *Comprehension* were used in analyses.

Woodcock Reading Mastery Tests–Revised/Normative Update (Woodcock, 1998): The *Passage Comprehension* subtest was administered, which requires participants to read passage of text and use a cloze procedure to fill in empty blanks in each passage. Standard scores were used to determine group membership, and in analyses.

Executive Function Measures—A wide range of executive function skills were sampled in our choice of instruments in order to capture the range of functions salient to the development of word recognition and reading comprehension. Descriptions of executive function tests and their hypothesized emphasis (component) within the executive function construct are listed in Table 1 and are described in more detail in the following.

Executive Functions—Working Memory

Sentence Span (Swanson, Cochran, & Ewers, 1989; based on Daneman & Carpenter, 1980): On this test, the examiner reads a set of sentences and asks a question about one of them. The child answers and then remembers the last word of each sentence. The number of sentences increases by one sentence with each set. The score for total number of words recalled was used in analyses.

Spatial Span (WISC-III–Process Instrument; WISC-III-PI; Kaplan, Fein, Kramer, Delis, & Morris, 1999): This measure uses a spatial span board, upon which 10 blue cubes are mounted in a random order. The researcher taps cubes (one cube per second) in a specified sequence, and the child is asked to replicate the sequence, both forward and backward. Scaled scores from the *Backward Span* trial were used in analyses.

Digit Span (WISC-IV; Wechsler, 2003): Children are asked to repeat aurally presented digit strings, both forward and backward. Scaled scores from the *Backward Span* trial were used in analyses.

Executive Functions—Planning, Organization, Self-Monitoring

Elithorn Mazes (WISC-III-PI; Kaplan et al., 1999): This measure requires the child to examine a visually presented maze and choose a single path that passes through circles within a "lattice" of lines in an inverted triangular structure, without backtracking. The measure provides information about strategic planning and response organization skills. Scaled scores were used in analyses.

Trail Making (Delis-Kaplan Executive Function System; D-KEFS; Delis, Kaplan, & Kramer, 2001): The entire D-KEFS *Trail Making Test* was administered; however, scaled scores from *Trial 4: Number/Letter Sequencing*, for which the participant was required to switch back and forth between connecting numbers and letters in sequence, were used in analyses.

Tower (D-KEFS; Delis et al., 2001): The Total Achievement Score from the *Tower Test*, a measure of a novel problem solving that requires planning and organization, was also administered. For this task, participants must move disks varying in size across three pegs to build a designated tower using the fewest number of moves possible.

Executive Functions—Response Inhibition

Conflicting motor response: This test was adapted from the *Luria-Christensen Battery* (Christensen, 1975) and has been used to examine motor response inhibition deficits in children (Mahone et al., 2006). Participants were told, "If I show you my finger, you show me your fist. If I show you my fist, you show me your finger." Examiners presented each of two gestures 24 times (a total of 48) with the right hand in pseudorandom sequence, at a rate of one per second. Number of correct responses were recorded (range = 0–48).

Contralateral motor response: This test has been used to study response inhibition in ADHD (Cole, Mostofsky, Gidley Larson, Denckla, & Mahone, 2008; Mahone et al., 2006). With eyes closed, participants were told to lift their right hand when touched on the left and lift their left hand when touched on the right, thus requiring inhibition of a prepotent motor response. A total of 48 trials were administered (24 for each hand) in random sequence. Number of correct responses were recorded (range = 0–48).

Data Analyses

First, the three groups (controls, WRD, S-RCD) were compared on demographic and screening variables using ANOVA for continuous variables and chi-square tests for categorical variables. Second, an exploratory principal components analysis was used to determine the latent factor structure of the eight executive function measures. As the purpose of the study was to compare group differences on these executive function components, a series of planned contrasts was then made on the resulting latent variables (i.e., the latent executive function components) using ANCOVAs (covarying for SES and ADHD symptom severity). When group differences were observed on a latent executive function factor, follow-up univariate ANCOVAs were used to examine group differences on the tests loading on that factor. Finally, in an effort to understand whether any executive function deficits in WRD were the by-product of the core deficits linked to basic word recognition deficits, we re-ran all analyses covarying for phonological processing.

Results

Sample Characteristics

Demographic information and behavioral screening measures are listed in Table 2. A total of 86 children participated in the study (24 control, 44 WRD, 18 S-RCD). There were no significant differences in age, $F(2, 83) = 0.27$, $p = .77$, among the three groups. When examining the sex ratio among the three groups, there were no significant differences, $\chi^2 = 1.38$, $p = .50$; there were 15 boys in the control group, 9 boys in the S-RCD group, and 29 boys in the WRD group. Our research criteria for diagnosis of ADHD included a *T*-score of 65 or greater on the *DSM-IV Hyperactive/Impulsive or Inattentive Scale* of the *Conners' Parent Rating Scale* or met criteria on the *ADHD Rating Scale IV–Home Version* (6/9 items scored 2 or 3 from *Inattention* and/or 6/9 items scored 2 or 3 from *Hyperactivity/Impulsivity* items). Of the participants, 4 children in both the control and S-RCD groups met research criteria for ADHD, while 15 children in the WRD group met research criteria for ADHD; there were no significant differences between the three groups in proportion of children with ADHD, $\chi^2 = 2.64$, $p = .27$. In addition, there was a trend for group differences in parent ratings of core ADHD symptom severity, namely, *Conners' Parent Rating Form Revised*, *DSM-IV: Total Score* ($p = .06$), which was driven by the WRD group being rated higher than controls ($p = .04$). Thus, to address potential effects of including children with ADHD across groups, global ADHD symptom severity (CPRS-R *DSM-IV: Total Score*) was used as a covariate in ANCOVAs examining group differences in the three identified latent factors.

There were also significant group differences in SES, $F(2, 83) = 5.55$, $p = .005$, with controls having higher SES than both the WRD and S-RCD groups (both $p < .01$), who were not different from one another. As such, SES was used as a covariate in subsequent analyses. There were also significant group differences in FSIQ, $F(2, 83) = 31.73$, $p < .001$, with the controls having higher FSIQ than both WRD and S-RCD groups (both $p < .001$). Given the overlap between components of IQ and EF (especially involving working memory and response preparation/processing speed), covarying for FSIQ is not appropriate when measuring group differences on executive functioning (Dennis et al., 2009). In addition, a recent meta-analysis of the effects of attention deficits on IQ assessment noted that children with ADHD taking short-acting stimulant medications had a mean increase of 6 to 7 IQ points compared to stimulant-naïve children who had been tested, suggesting that reduced IQ scores relative to typically developing peers may be driven by attentional problems and suboptimal test-taking behavior rather than reduced intelligence (Jepsen, Fagerlund, & Mortensen, 2009). In addition, IQ test scores may be lowered by RD–associated language, working memory, or processing speed deficits. Finally, components of the IQ score (e.g., *Digit Span*) were used as dependent measures in the current study. Thus, covarying for IQ would likely limit the sensitivity of analyses when examining related measures of interest in the present study (i.e., working memory).

After controlling for SES, there was a significant group difference for parent ratings on the BRIEF *Global Executive Composite* score, $F(2, 79) = 7.29$, $p = .001$; post hoc test (Tukey's honestly significant difference test) revealing the WRD group being rated by parents as having greater executive dysfunction than both the control ($p = .002$) and the S-RCD groups ($p = .004$). The control and S-RCD groups did not differ on parent BRIEF ratings ($p = .99$). There was also a significant difference between groups on the CTOPP *Phonological Processing Composite*, $F(2, 81) = 26.50$, $p < .0001$, with both control ($p = .0001$) and S-RCD groups ($p = .0001$) scoring higher than the WRD group but similar to each other ($p = .11$). As expected, there were significant differences between groups on the WRMT-R/NU *Basic Skills Cluster*, $F(2, 82) = 114.71$, $p < .001$, with both control ($p = .0001$) and S-RCD groups ($p = .0001$) having higher scores than the WRD group; there was no difference between the control and S-RCD groups ($p = .187$).

There were significant differences between groups on both measures of fluency. On the SWE subtest from the TOWRE, $F(2, 82) = 35.31$, $p < .001$, the WRD group's scores were significantly lower than both the control and S-RCD groups ($p < .001$). The WRD group's performance on the OWPC, $F(2, 82) = 17.07$, $p < .001$, was also significantly poorer than the control ($p < .001$) and S-RCD groups ($p = .001$). There were no differences between the control and S-RCD groups on the TOWRE ($p = .556$) or the OWPC task ($p = .116$).

Reading comprehension scores also differed by group after controlling for SES and severity of ADHD symptoms. Significant differences were found on SDRT-4 *Reading Comprehension*, $F(2, 79) = 60.88$, $p < .001$; DAB *Reading Comprehension*, $F(2, 82) = 25.33$, $p < .001$; the GORT-IV *Comprehension* test, $F(2, 82) = 23.68$, $p < .001$; and the *Gates-MacGinitie Reading Tests Comprehension* scores, $F(2, 79) = 59.43$, $p < .001$. On all four measures, the controls outperformed both the WRD (p = .0001) and S-RCD groups ($p = .0001$), who did not differ from each other. Analysis of and WRMT-R/NU *Passage Comprehension*, $F(2, 83) = 53.15$, $p < .001$, revealed that controls performed better than WRD ($p = .0001$) and S-RCD groups ($p = .0001$) on both, while the S-RCD group performed better than the WRD group on WRMT-R/NU *Passage Comprehension* ($p = .\ 0001$).

Latent Components of Executive Function

A principal components analysis (varimax rotation) was used to explore the latent factor structure of the eight executive function variables. The resulting factor loadings are listed in Table 3. The factor analysis yielded three factors, which accounted for 62.9% of the total variance. Variables loading on Factor 1 (29.6%) emphasized planning/spatial working memory (*Elithorn Mazes*, *Trail Making Number/Letter Sequencing*, *Tower*, and *Spatial Span*), variables loading on Factor 2 (16.6%) emphasized verbal working memory (*Digit Span, Sentence Span*), while variables loading on Factor 3 (16.6%) emphasized response inhibition (*Conflicting Motor Response* and *Contralateral Motor Response*). These resulting three latent factors (named Planning, Verbal Working Memory, and Response Inhibition factors for analyses) were used as dependent measures for group contrasts in the following.

Group Comparisons on EF Component Factors

Means, standard deviations, and group comparisons for all measures are listed in Table 4. After controlling for SES and ADHD symptom severity, ANCOVAs revealed significant group differences on all three latent EF factors: Planning/ Spatial Working Memory, $F(2, 79) = 3.16$, $p = .048$, $\eta^2_{p.} = .074$; Verbal Working Memory, $F(2, 79) = 4.60$, $p = .013$, $\eta^2_p = .10$; and Response Inhibition, $F(2, 79) = 3.05$, $p = .053$; $\eta^2_p = .072$. Follow-up planned contrasts between groups are reported in the following.

WRD Versus Controls

After controlling for SES and ADHD symptom severity, children with WRD had significantly reduced performance, compared to controls, on the Verbal Working Memory factor, $F(1, 63) = 8.1$, $p = .006$, $\eta^2_p = .114$. Planned contrasts of tests comprising this factor indicating reduced performance on *Digit Span Backward* ($p = .001$) in the WRD group. The WRD group also had poorer performance than controls on the Response Inhibition factor, $F(1, 63) = 5.18$, $p = .026$, $\eta^2_p = .076$; planned contrasts highlighted a significantly greater number of errors by the WRD group on *Conflicting Motor Response* ($p = .02$). The WRD and control groups did not differ on the Planning/ Spatial Working Memory factor, $F(1, 63) = 2.2$, $p = .145$, $\eta^2_p = .033$.

S-RCD Versus Controls

After controlling for SES and ADHD symptom severity, children with S-RCD had significantly reduced performance (compared to controls) on the Planning factor, $F(1, 37) = 4.04$, $p = .05$,

η^2_p = .098. Follow-up planned contrasts of the tests comprising this factor indicated significantly reduced performance on the D-KEFS *Tower* (p = .02) and *Spatial Span Backwards* (p = .04). Controls and S-RCD groups were not significantly different on the Verbal Working Memory factor, $F(1, 37) = 1.08$, $p = .305$, $\eta^2_p = .028$. There was a trend toward reduced performance among the S-RCD group Response Inhibition factor, $F(1, 37) = 3.65$, $p = .063$, $\eta^2_p = .090$.

WRD Versus S-RCD

After controlling for SES and ADHD symptom severity there were no significant differences between the WRD and S-RCD groups on the Response Inhibition, $F(1, 56) = 0.29$, $p = .865$, $\eta^2_p = .001$, or Verbal Working Memory, $F(1, 56) = 2.17$, $p = .147$, $\eta^2_p = .037$, factors; but there was a trend for the S-RCD group to perform more poorly than the WRD group on the Planning factor, $F(1, 56) = 3.90$, $p = .084$, $\eta^2_p = .052$.

Exploratory Analyses: S-RCD Group

Since one purpose of this study was to clarify the underlying executive function profiles in children with S-RCD, a set of supplementary exploratory analyses was conducted using the process variables from the D-KEFS *Tower* test (see Table 5). Our previous study (Cutting et al., 2009) also reported that children with S-RCD performed particularly poorly on a computerized version of the Tower of London test, showing a significant number of excess moves compared to both WRD and control groups (with the WRD and control groups performing similarly). In the present study, use of the D-KEFS *Tower*, which has process variables, allowed for a more finegrained analysis of these previous findings, potentially elucidating strategic factors (adaptive or maladaptive) used by participants as they approached this novel task (Wodka et al., 2008). Two process scores for the *Tower* test were included: (a) move accuracy ratio (analogous to excess moves in the Cutting et al., 2009, study) and (b) rule violations per item ratio. After controlling for SES and ADHD symptom severity, there were significant differences observed among the three groups on both variables: move accuracy ratio, $F(2, 79) = 4.95$, $p = .009$, $\eta^2_p = .11$, and rule violations per item, $F(2, 79) = 4.26$, $p = .018$, $\eta^2_p = .10$. Follow-up planned contrasts indicated that children with S-RCD had a reduced move accuracy ratio compared to controls, $F(1, 37) = 4.82$, $p = .034$, $\eta^2_p = .115$, and the WRD group, $F(1, 56) = 9.61$, $p = .003$, $\eta^2_p = .15$, suggesting that they made more incorrect moves relative to correct moves. The S-RCD also had a lower rule violations per item ratio score than the controls, $F(1, 37) = 4.85$, $p = .034$, $\eta^2_p = .116$. To examine whether our findings on the D-KEFS *Tower* process variables were indeed specific to the S-RCD group, we also compared the WRD and control group on the process scores; results showed that, consistent with the Cutting et al. (2009) findings, the WRD and control group comparison showed no significant differences on the move accuracy ratio score. However, the WRD group had more rule violations per item than controls: rule violations per item ratio, $F(1, 63) = 6.68$, $p = .012$, $\eta^2_p = .096$.

Analyses Covarying for Phonological Processing

All analyses were recomputed after covarying for the CTOPP phonological processing composite (in addition to SES and ADHD symptom severity). Results indicated that the only significant group difference was for the control versus S-RCD contrast on the Planning factor, $F(1, 36) = 4.11$, $p = .05$, $\eta^2_p = .103$. None of the other factor scores were significantly different for the control versus WRD or WRD versus S-RCD contrasts. Follow-up analyses contrasting the control and S-RCD groups on the individual tests comprising the Planning factor showed a statistically significant result for the D-KEFS *Tower*, $F(1, 36) = 6.58$, $p = .015$, $\eta^2_p = .155$. Finally, after covarying for phonological processing (as well as SES and ADHD symptom severity) for the D-KEFS *Tower* process variables, the analyses yielded similar results to those that did not covary for phonological processing, with the S-RCD group showing lower performance than both the control, $F(1, 36) = 6.62$, $p = .014$, $\eta^2_p = .155$, and WRD, $F(1, 54) = 6.18$, $p = .016$, $\eta^2_p = .103$, groups on move accuracy ratio, and the WRD group still showing more rule violations per item ratio as compared to the control group, $F(1, 61) = 7.10$, $p = .01$, $\eta^2_p = .104$. The S-RCD group also continued to show lower performance on the rule violations per item ratio as compared to the control group, $F(1, 36) = 5.67$, $p = .023$, $\eta^2_p = .136$.

Discussion

Results of the present study demonstrate that children with reading disorders perform poorly on executive function measures. In particular, those children with basic word recognition deficits (most of whom had concomitant deficits in reading comprehension) demonstrated pronounced executive dysfunction across skill areas involving verbal working memory and response inhibition. However, executive dysfunction in WRD group appears in part to be linked to weaknesses in phonological processes, as this group showed less EF impairment after covarying for phonological processing. These results are consistent with Baddeley's model of an executive system modulated by phonological input (Baddeley & Hitch, 1974; Gathercole & Baddeley 1993). Thus, while children with WRD may present with executive dysfunction, our findings indicate that these deficits may in part stem from their core difficulties in phonological processing.

Even though the pattern of results in the WRD group suggested their executive function skills are modulated to a certain extent by phonological processing, our findings on the whole strongly suggest that the relationship between executive dysfunction and reading comprehension does not appear to stem solely from processes underlying word recognition, as those children with specific reading comprehension deficits (i.e., those without basic word recognition deficits) demonstrated executive dysfunction in strategic planning, even when phonological processing performance was controlled for in analyses. These results highlight the contribution of executive function skills (over and above skills necessary for basic reading) in the development of reading comprehension and are consistent with the findings of Cutting et al. (2009) as well as Sesma et al. (2009), who demonstrated this unique contribution in separate cohorts.

Further evidence was found to support the specific role of strategic planning in reading comprehension in that the children with reading comprehension deficits performed poorly in this area while children with WRD did not. These deficits remained after controlling for the contribution of ADHD symptoms. In particular, the S-RCD group had the lowest performance on the D-KEFS *Tower* test and *Spatial Span Backwards*.

When we further examined the process variables associated with the D-KEFS *Tower*—a measure emphasizing *spatial* planning, rule learning, and the ability to establish and maintain an instructional set (skills that appear to be in particular significantly linked to reading comprehension performance)—we found some distinctions between groups. In the WRD group, their performance was lower (although still within the average range) on the aspect of the D-KEFS *Tower* that required adhering to rules (rule violations), suggesting set loss; this finding may stem from less efficient ability to hold the rules in verbal working memory. While the S-RCD group also showed lower performance (but again within the average range) on rule violations, the most prominent differences on D-KEFS *Tower* appeared to be related to planning errors. Overall, the D-KEFS *Tower* findings with regard to S-RCD suggest an underlying inefficiency in the planning and organization needed for a particular task; these deficits may underlie the manner in which children with S-RCD navigate and organize reading material for comprehension. In fact, studies have shown that *monitoring* during reading (e.g., Oakhill & Yuill, 1996; Perfetti et al., 1996; Ruffman, 1996) and the organization of reading material (e.g., Cornoldi, DeBeni, & Pazzaglia, 1996) are predictive of reading comprehension. Furthermore, these results replicate our previous findings of an S-RCD group showing greater excess moves as compared to both WRD and control groups (Cutting et al., 2009) and thus provide converging evidence that this particular type of strategic planning is linked to reading comprehension.

Strengths of the study include the use of a broad range of executive function measures and the inclusion of common comorbidities (e.g., ADHD) in all three groups. In addition, it is important to note the careful characterization of reading performance in all three groups; in particular, the current study used a more rigorous operationalization of S-RCD (i.e., poor performance on at least two out of five measures of reading comprehension) than previous studies, thus further suggesting the specificity of linkages between planning and organization deficits and poor reading comprehension. The study also highlights the importance of comparing two distinct groups of children with comprehension problems (i.e., those with and without word recognition deficits) not only to each other, but concurrently to contemporaneously recruited groups of children with average reading skills.

Limitations of the study include the unequal sample size among groups, which may have reduced statistical power in the S-RCD group contrasts. It should be noted that in general, while there were a greater number of significant group differences among EF variables (compared with controls) in the WRD group than the S-RCD group, this discrepancy may have been in part due to the larger sample size in the WRD group ($n = 44$) compared to the S-RCD group ($n = 18$). In fact, when examining effect sizes versus statistical significance for group contrasts among the latent EF factors, slightly different patterns of executive dysfunction emerged. While the S-RCD group clearly had a slightly greater relative deficit than the WRD group on planning variables, the two groups had essentially equal relative deficits on response inhibition. The WRD group, in contrast, had a greater relative deficit in verbal working memory than the S-RCD group; these findings are possibly related to deficits in phonological processing, or perhaps due to a slightly larger proportion of children with ADHD in the WRD group as there were higher (more impaired) parent ratings of executive dysfunction in the WRD group than the S-RCD group.

It also should be noted that although the inclusion of common comorbidities (e.g., ADHD) in all three groups likely leads to a realistic representation of real-life skills and difficulties, there remains an incomplete double dissociation between ADHD and RD. While we address the effects of ADHD symptomatology statistically, future research will be required to determine whether similar patterns of EF skill and weakness exist among children with S-RCD and WRD who do *not* have comorbid ADHD. Furthermore, our research criteria for ADHD included only the *DSM-IV Hyperactive/Impulsive and Inattentive Scale* of the *Conners' Parent Rating Scale or* the *ADHD Rating Scale IV–Home Version* and did not include teacher forms or more structured diagnostic interviews. Future studies should include a multiple-method and multiple-trait approach to more thoroughly identify ADHD symptoms and their overlap with components of executive control difficulties among children with S-RCD.

Given that Cutting et al. (2009) found that participants with S-RCD scored lower than controls and similarly to children with WRD on oral language measures, future research should also attempt to examine the interaction of executive function skills and language-based abilities, for example, syntactic and semantic skills, and especially higher-order inferential language skills (which may have significant overlap with EF), as predictors of reading comprehension. In this regard, it will be interesting to compare findings in the current age group (i.e., 10–14 years) with potential executive function and reading comprehension deficits in older age groups, as executive processing continues to develop through adolescence (Asato, Sweeney, & Luna, 2006).

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Table 1

Executive Function Measures Examined in the Study

Hypothesized Executive Function Component	Tests
Working memory	*Sentence Span*
	Digit Span Backward Span (WISC-IV)
	Spatial Span Backward Span (WISC-III-PI)
Planning/spatial working memory	*Elithorn Perceptual Maze Test* (WISC-III-PI)
	Trail Making (Letter/Number Sequencing; D-KEFS)
	Tower (Total Achievement; D-KEFS)
Response inhibition	*Conflicting Motor Response Test*
	Contralateral Motor Response Test

Note: WISC-IV = *Wechsler Intelligence Scale for Children, Fourth Edition;* WISC-III-PI = *Wechsler Intelligence Scale for Children, Third Edition Process Instrument;* D-KEFS = *Delis-Kaplan Executive Function System*.

Table 2

Demographic and Screening Variables

	Control (a; n = 24)		WRD (b; n = 44)		S-RCD (c; n = 18)		ANOVA	
	M	***SD***	***M***	***SD***	***M***	***SD***	***p***	**Planned Contrasts**
Demographic information								
Age	11.82	1.29	11.85	1.40	11.59	1.15	.768	
SES	1.39	0.49	1.92	0.87	2.13	0.83	.005	a > b**, a > c**
FSIQ	111.39	7.32	92.07	10.74	93.33	10.75	.000	a > b**, a > c**
Conners' DSM-IV:Total Scale	53.88	10.54	60.14	11.59	53.94	13.74	.058	
BRIEF GEC	52.62	10.92	60.76	10.19	51.18	12.51	.001	a > b**, c > b**
Phonological processing/ word recognition/fluency								
CTOPP *Phonological Processing*	98.75	7.60	85.53	7.07	94.33	6.65	.000	a > b**, c > b**
WRMT-R/NU *Basic Skills Cluster*	104.00	4.42	83.82	6.50	101.61	5.50	.000	a > b**, c > b**
TOWRE SWE	102.12	8.54	83.28	10.62	100.06	8.82	.000	a > b**, c > b**
OWPC	68.05	7.27	56.69	10.66	65.59	7.12	.000	a > b**, c > b**
Reading comprehension								
SDRT-4 *Reading Comprehension*	7.00	1.31	2.88	1.40	3.22	1.59	.000	a > b**, a > c**
GMRT *Comprehension*	7.08	1.50	2.37	1.79	3.28	1.27	.000	a > b**, a > c**
DAB *Reading Comprehension*	11.04	1.49	6.52	2.60	6.44	2.60	.000	a > b**,a > c**
GORT-4 *Comprehension*	12.46	1.96	8.23	2.33	9.06	2.46	.000	a > b**,a > c**
WRMT-R/NU *Passage Comprehension*	109.46	6.97	85.32	11.09	96.67	5.47	.000	a > b**, a > c**, c > b**

Note: WRD = word recognition deficits; S-RCD = specific reading comprehension deficit; SES = socioeconomic status *(Hollingshead Four Factor Index);* FSIQ = *Wechsler Intelligence Scale for Children, Fourth Edition Full Scale Intelligence Quotient; Conners' Parent Rating Form Revised, DSM-IV:*Total Score; BRIEF GEC = *Behavioral Rating Scale of Executive Functioning Global Executive Composite;* CTOPP = Comprehensive Test of Phonological; WRMT-R/NU = *Woodcock Reading Mastery Test–Revised/Normative Update* Standard Scores; TOWRE SWE = *Test of Word Reading Efficiency–Sight Word Efficiency* Standard Score; OWPC = *Orthographic Word-Pseudohomophone Choice* Number Correct; SDRT-4 = *Stanford Diagnostic Reading Test Stanine, Fourth Edition;* GMRT = *Gates-MacGinitie Reading Tests* Stanine; DAB = *Diagnostic Achievement Battery* Scaled Score; GORT-4 = *Gray Oral Reading Test Scaled Score, Fourth Edition.*

* $p < .05$.

** $p < .01$.

Table 3

Factor Analysis for Executive Function Variables

	Component		
Measure	**1**	**2**	**3**
Mazes	**0.823**	0.200	0.011
Spatial Span	**0.820**	0.179	−0.075
Tower	**0.727**	−0.039	0.119
Trail Making	**0.621**	0.249	0.270
Digit Span	0.184	**0.752**	0.143
Sentence Span	0.133	**0.703**	−0.123
Conflicting	−0.043	0.215	**0.853**
Contralateral	0.229	−0.300	**0.687**

Note: Figures in bold represent the three identified factors. Mazes = *Elithorn Perceptual Mazes Test Scaled Score (Wechsler Intelligence Scale for Children,Third Edition, Process Instrument*; WISC-III-PI); Spatial Span = *Spatial Span Backward Span Scaled Score* (WISC-III-PI); Tower = *Delis-Kaplan Executive Function System* (D-KEFS) *Tower Total Achievement Scaled Score*; Trail Making = *Trail Making Letter/Number Sequencing Scaled Score* (D-KEFS); Digit Span = *Digit Span Backward Span Scaled Score* (Wechsler *Intelligence Scale for Children, Fourth Edition*; WISC-III-PI); Sentence Span = *Sentence Span Total Words Recalled*; Conflicting = *Conflicting Motor Response Test Number Correct*; Contralateral = *Contralateral Motor Response Test Number Correct*.

Table 4

Group Comparisons for Executive Function Components

EF Component/Factor	Tests Loading on Factor	Control (*n* = 24) *M*	Control (*n* = 24) *SD*	WRD (*n* = 44) *M*	WRD (*n* = 44) *SD*	S-RCD (*n* = 18) *M*	S-RCD (*n* = 18) *SD*	Omnibus ANCOVA *p*	Omnibus ANCOVA η^2_p	Planned Contrasts: WRD Versus Control *p*	Planned Contrasts: WRD Versus Control η^2_p	Planned Contrasts: S-RCD Versus Control *p*	Planned Contrasts: S-RCD Versus Control η^2_p
Planning/Spatial Working Memory Factor		**0.41**	**0.77**	**−0.65**	**0.97**	**−0.43**	**1.23**	**.048**	**.074**	**.15**	**.03**	**.05**	**.10**
	Mazes	11.25	2.70	9.43	3.16	8.89	3.77					.13	.06
	Trail Making	10.09	2.64	7.64	3.95	8.05	3.56					.13	.06
	Tower	11.00	2.30	9.86	2.26	8.83	2.04					.02	.14
	Spatial Span	10.08	1.98	9.17	2.68	8.00	3.51					.04	.11
Verbal Working Memory Factor		**0.54**	**1.02**	**−0.34**	**0.89**	**0.02**	**0.95**	**.013**	**.104**	**.01**	**.11**	**.31**	**.03**
	Digit Span	10.73	2.09	8.15	2.26	9.33	2.61			.00	.15		
	Sentence Span	6.15	1.94	5.28	2.08	5.35	1.45			.19	.03		
Response Inhibition Factor		**−0.35**	**0.69**	**−0.20**	**0.93**	**−0.11**	**1.38**	**.053**	**.072**	**.03**	**.08**	**.06**	**.09**
	Conflicting	43.04	2.66	41.24	3.63	40.82	4.16			.02	.08	.04	.10
	Contralateral	43.74	1.84	43.08	2.54	43.35	3.97			.67	.00	.68	.00

Note: Figures in bold represent statistically significant values ($p<.05$).All ANCOVAs are controlling for socioeconomic status (*Hollingshead Index*) and *Conners' Parent Rating Form Revised, DSM-IV:*Total Score. EF = executive function;WRD = word recognition deficits; S-RCD = specific reading comprehension deficit. Digit Span = *Digit Span Backward Span Scaled Score (Wechsler Intelligence Scale for Children, Fourth Edition*; WISC-IV); Spatial Span = *Spatial Span Backward Span Scaled Score (Wechsler Intelligence Scale for Children. Third Edition, Process Instrument*; WISC-III-PI); Sentence Span = *Sentence Span Total Words Recalled;* Mazes = *Elithorn Perceptual* Mazes Test *Scaled Score* (WISC-III -PI);Trail Making = *Trail Making Letter/Number Sequencing Scaled Score (Delis-Kaplan Executive Function System;* D-KEFS); Tower = D-KEFS *Tower Total Achievement Scaled Score;* Conflicting = *Conflicting Motor* Response Test *Number Correct;* Contralateral = *Contralateral Motor Response Test Number Correct*.

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Table 5

Group Comparisons for *Delis-Kaplan Executive Function System* Tower Process Variables

							Planned Contrasts					
	Control (*n* = 24)		**WRD (*n* = 44)**		**S-RCD (*n* = 18)**		**WRD Versus Control**		**S-RCD Versus Control**		**WRD Versus S-RCD**	
Process Variable	***M***	***SD***	***M***	***SD***	***M***	***SD***	***p***	η^2_p	***p***	η^2_p	***p***	η^2_p
Move accuracy ratio	9.45	2.32	9.66	2.62	7.12	3.53	.471	.008	.034	.115	.003	.146
Rule violations per item ratio	10.44	.65	9.33	2.13	9.94	.73	.012	.096	.034	.116	.242	.024

Note: All ANCOVAs are controlling for socioeconomic status *(Hollingshead Index)* and *Conners'Parent Rating Form Revised*, *DSM-IV:*Total Score. Process variables are reported in scaled scores. WRD = word recognition deficits; S-RCD = specific reading comprehension deficit.