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Effects of fluency, oral language, and executive function on reading comprehension performance

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Abstract Reading disability (RD) typically consists of deficits in word reading accuracy and/or reading comprehension. While it is well known that word reading accuracy deficits lead to comprehension deficits (general reading disability, GRD), less is understood about neuropsychological profiles of children who exhibit adequate word reading accuracy but nevertheless develop specific reading comprehension deficits (S-RCD). Establishing the underlying neuropsychological processes associated with different RD types is essential for ultimately understanding core neurobiological bases of reading comprehension. To this end, the present study investigated isolated and contextual word fluency, oral language, and executive function on reading comprehension performance in 56 9- to 14-year-old children [21 typically developing (TD), 18 GRD, and 17 S-RCD]. Results indicated that TD and S-RCD participants read isolated words at a faster rate than participants with GRD; however, both RD groups had contextual word fluency and oral language weaknesses. Additionally, S-RCD participants showed prominent weaknesses in executive function. Implications for understanding the neuropsychological bases for reading comprehension are discussed.

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It is well established that many children and adolescents have inadequate reading comprehension (NAEP, 2003). Because comprehension of text is the ultimate goal of the reader, difficulty in reading comprehension has far-reaching consequences not just for school achievement but also for a student's future educational and occupational opportunities. Until recently, many researchers assumed that bottom-up skills (word recognition and decoding) were the predominate reason for difficulty with reading comprehension. Indeed, various independent researchers have demonstrated that if a reader is seriously deficient at decoding and recognizing words, this will necessarily impede successful comprehension (see Lyon, 1995; Torgesen, 2000). Furthermore, it is thought that not just accuracy in bottom-up skills is important but also their efficiency or speed as well. Slow word reading increases demands placed on other processes, such as working memory, which in turn poses difficulties for comprehending connected text and thus creates a processing bottleneck (e.g., Perfetti & Hogaboam, 1975; Perfetti, Marron, & Foltz, 1996; Wolf & Katzir-Cohen, 2001; Shankweiler, 1999).

Other lines of research, however, suggest that reading comprehension deficits can arise for multiple distinct reasons, which include, but are not limited to, weaknesses in bottom-up skills (Cain & Oakhill, 2006; Catts, Fey, Zhang, & Tomblin, 1999; Biancarosa & Snow, 2004; Catts, Hogan, Adof, & Barth, 2003a; Leach, Scarborough, & Rescorla, 2003; McCardle, Scarborough, & Catts, 2001; Nation & Snowling, 2000, 1998; Scarborough, 1990, 2005; Snow, 2002). This is especially illustrated by the population of children who have specific reading comprehension deficits (S-RCD, i.e., poor comprehension in spite of apparent absence of weaknesses in bottom-up skills). According to several studies, about 3–10% of school-aged children display this reading profile (e.g., Aaron, Joshi, & Williams, 1999; Catts, Hogan, & Fey, 2003b; Leach et al., 2003; Nation, 2001; Torppa et al., 2007). These findings suggest that components other than efficient word recognition, not all of which have been fully identified, are likely to make a substantial contribution to reading comprehension.

Within this context, the central purpose of this study was to examine bottom-up (word level) and top-down (or higher level cognitive) processes as related to comprehension to understand more about reading comprehension failure. To examine this issue, we selected three types of readers [typically developing (TD), those with general reading deficits (GRD), and those with S-RCD] and measured their fluency, oral language, and executive functioning processes. These groups and constructs were chosen to address the following competing hypotheses: (1) comprehension failure is primarily due to a processing bottleneck even in poor comprehenders with *apparent* normal word recognition/decoding abilities (i.e., readers who are *accurate* in these bottom-up skills; S-RCD) or (2) bottom-up processes cannot fully explain reading comprehension failure, and therefore, other higher level processes in the oral language and executive function domains, either in isolation or in combination, are associated with reading comprehension failure.

It is important to mention that we chose to examine these particular constructs because we were especially interested in understanding potential components of higher level comprehension processes within a neuropsychological framework. Although there are clearly many important and influential models and studies of reading comprehension (e.g., Kintsch, 1998; Schmalhofer & Perfetti, 2007), to date, these research studies have not always been comprehensively connected to the neuropsychological literature. Linking underlying neuropsychological processes associated with different types of readers to the rich body of literature on reading comprehension is essential for ultimately understanding underlying neurobiological bases of reading comprehension. Previous findings suggest that additional neuropsychological processes above and beyond bottom-up processes, including oral language and executive function, account for a substantial amount of variance in reading comprehension (e.g., Catts et al., 1999; McCardle et al., 2001; Nation & Snowling, 1998; Scarborough, 1990; Sesma, Mahone, Levine, Eason, & Cutting 2008; Swanson, 1999). While some studies have examined one or two of the aforementioned processes as related to reading comprehension, as of yet, no studies have examined all of these processes in the same children separated into groups with either GRD or S-RCD within a single study. Such examination is critical for our understanding of underlying neuropsychological processes that impair reading comprehension and is an important step towards beginning to link existing comprehensive cognitive models of reading comprehension with brain function. We review each of the neuropsychological constructs included in our examination of reading comprehension in more detail below.

Fluency

While many researchers have investigated the role of word recognition/decoding accuracy in reading comprehension, the construct of fluency has not always been considered, particularly as related to S-RCD. Fluency, which is commonly operationalized as word reading speed, is a critical element in reading comprehension (LaBerge & Samuels, 1974; Perfetti & Hogaboam, 1975; Perfetti et al., 1996). Grasping meaning from reading passages is thought to be deterred by slow and labor-intensive reading because a bottleneck effect occurs in which there is competition between higher level versus word-level processes (Shankweiler, 1999). Therefore, measuring fluency is important in determining whether poor reading comprehension among children with S-RCD is a result of the bottleneck effect or whether these children truly have solid (i.e., fast and efficient) word-level skills. Although some investigators have measured fluency and have found evidence of S-RCD despite normal word reading speed (e.g., Barnes, Faulkner, & Dennis, 2001; Leach et al., 2003; Stothard & Hulme, 1995), most studies of S-RCD have not examined fluency in addition to accuracy (e.g., Cain, 2006; Cain, Oakhill, & Bryant, 2004; Catts et al., 1999, 2003b). Thus, the extent to which a bottleneck may occur and impede comprehension is still open for question in the S-RCD population. Furthermore, few studies of S-RCD have examined fluency in a comprehensive manner that includes both isolated word *and* contextual fluency measures. Measuring both of these approaches may be important because there is suggestion that distinctions may need to be made between these two types of fluency. For example, a study conducted by Jenkins, Fuchs, Van den Broek, Espin, and Deno (2003a) investigated a sample of fourth grade students and found that contextual word reading speed uniquely predicted reading comprehension, whereas isolated word reading speed did not. Most recently, Klauda and Guthrie (2008) examined various levels of fluency (word, syntactic, and passage) and found that isolated word fluency was associated with bottom-up skills, while contextual fluency was related to higher level skills in reading comprehension. Therefore, when examining bottom-up and top-down processes related to reading comprehension deficits, particularly in S-RCD, the role of contextual word reading speed versus isolated word reading speed may be an important consideration.

Oral language

The influence of oral language skills on reading comprehension is widely documented; the well-known "simple view" model of reading (Gough & Tunmer, 1986) in particular illustrates the importance of oral language. This model attributes reading comprehension to two factors: decoding of printed words and language comprehension. Oral language such as vocabulary and syntax have been shown to influence reading comprehension performance (e.g., Catts et al., 1999; Cutting & Scarborough, 2006; Share & Leikin, 2004; Torgesen, 2000), although somewhat differently depending on the reading comprehension measure (Cutting & Scarborough, 2006; Francis et al., 2006; Keenan, Betjemann, & Olson, 2008). Additionally, studies in which researchers have specifically examined oral language skills in children with S-RCD have demonstrated the impact of oral language abilities on reading comprehension performance, including semantics (Nation & Snowling, 1998, 1999) and syntax (Nation & Snowling, 2000). Also supporting the role of these broader oral language abilities as related to reading comprehension are findings suggesting that oral language has a greater influence on reading comprehension than code-related skills (e.g., phonological processing), with the latter having a greater influence on word reading (Catts et al., 1999; Share & Leikin, 2004). Nevertheless, while there is evidence for oral language difficulties in children with reading disabilities, the exact nature and specifics of oral language difficulty across different types of poor readers (GRD and S-RCD) is not fully established. Therefore, further examination of this issue would contribute to developing a more extensive understanding of reading comprehension deficits. In our study, we were particularly interested in gaining better understanding correlates of comprehension problems when word-level difficulties were present versus absent.

Executive function

In contrast to the influence of fluency and language on reading comprehension, which has been heavily researched, relatively few studies feature components of executive function as related to reading comprehension. Executive function consists of higher order skills such as inhibition, working memory, planning, organizing, and self-monitoring, all of which are thought to be subserved by the frontal lobes, as evidenced by lesion studies showing that patients with dorsolateral and ventromedial prefrontal lesions have deficits in these areas of functioning (Shallice, 1982). It is important to note that while executive function deficits are typically thought of in association with attention deficit hyperactvity disorder (ADHD; Mahone et al., 2002a), executive dysfunction can also been seen independently of ADHD symptomology (e.g., Mangeot, Armstrong, Colvin, Yeates & Taylor, 2002; Mahone, Zabel, Levey, Verda & Kinsman, 2002b). While executive function has been hypothesized to be associated to reading comprehension (e.g., Berninger, 1994; Purvis & Tannock, 1997), only a few studies exist that feature an operalization of executive function by traditional neuropsychological methods (e.g., Sesma et al. 2008). While many reading comprehension studies have assessed skills that would theoretically involve executive function, such as self-monitoring and verbal working memory, most studies have not conceptualized these higher order skills as falling within the rubric of executive function. Specific executive skills that are proposed to influence reading comprehension performance include verbal and visual working memory, as well as the capacity to plan, organize, and monitor information (e.g., Cutting, Eason, Young, & Alberstadt, 2009; Daneman & Carpenter, 1980; Just & Carpenter, 1992; Swanson, 1999; Swanson & Alexander, 1997; Swanson & Trahan, 1996;

Swanson & Berninger, 1996; Swanson & Trahan, 1996; Oakhill & Yuill, 1996; Perfetti et al., 1996; Ruffman, 1996; Cornoldi, De Beni, & Pazzaglia, 1996; Sesma et al. 2008). The present study focused on tasks that measure verbal working memory as well as planning, organizing, and monitoring abilities. Past research indicates that monitoring during reading (e.g., Perfetti et al. 1996; Oakhill & Yuill, 1996; Ruffman, 1996), organizing reading material (e.g., Cornoldi et al., 1996), and working memory are predictive of reading comprehension (e.g., Swanson & Trahan, 1996; Swanson, 1999).

Current study

The aim of this study was to further understand, within a neuropsychological framework, the role of fluency of reading words in isolation and in context, oral language proficiencies, and executive function on reading comprehension performance in TD, GRD, and S-RCD students. A particular focus was to understand the degree of bottom-up process involvement in reading comprehension, especially for the children with S-RCD. More specifically, we aimed to address the following questions to explore the aforementioned issues:

1. Can poor reading comprehension in the S-RCD group be explained largely due to a processing bottleneck, as evidenced by weaknesses in bottom-up skills?
2. Does the S-RCD group show deficits in oral language or executive function? Is the degree to which these deficits are present in S-RCD more substantial in one or both domains (i.e., oral language and executive function) than both the GRD and/or TD readers? Finally, can ADHD symptomology explain executive function deficits (if present), particularly for the S-RCD group?
3. Is there support for separation of isolated versus contextual word fluency, or does performance on these measures across and within the three groups converge?
4. Do isolated and contextual word fluency, oral language, and executive function each contribute a significant amount of variance to reading comprehension? Does this contribution differ across reading comprehension measures?

Methods

Participants

Seventy-four children, ages nine to 14, were recruited through regional magazine advertisements, clinic referrals, and newsletters. Following an initial telephone screening and clinic visit, 56 children [(31 girls (55%), 25 boys (45%)] were eligible for participation. Participants ranged in age from 9 years, 2 months to 14 years, 11 months (mean and standard deviation of age was 11.84 and 1.48, respectively). Racial/ethnicity information was obtained for 39 participants; nine children were African American (23%), 28 were Caucasian (71%), one was Asian (3%), and one was biracial (3%).

Participants with a full-scale intelligence quotient (FSIQ)<80[1], a previous diagnosis of mental retardation, a known uncorrectable visual or hearing impairment, treatment of any

[1] In such cases when participants showed statistically significant differences in standard deviation between verbal and nonverbal estimates of IQ, the higher score was used; this was true for two participants. Additionally, we included two other participants who earned FSIQ estimates below 80 despite *not* exhibiting a statistically significant difference between verbal and performance indices; however, in both cases, at least one of their index scores was above 80.

psychiatric disorder with psychotropic medication, a diagnosis of developmental disability, a history of neurological impairment, and non-native English speakers were excluded from the study. Additionally, participants with basic reading standard scores between the 25th and 40th percentile were excluded from the study.

Group assignment Children were placed into one of three groups (TD, GRD, S-RCD) based on word reading and reading comprehension scores obtained during the screening visit, which are described in detail below. Prior to screening, parental reports indicated that children in the GRD group had either a preexisting diagnosis of a learning disability or indications that reading was problematic (e.g., parents noticed difficulties in reading, reading was noted to be below grade level, or the child was receiving tutoring). From the completed screening measures we collected, 18 children were included in the GRD group (eight girls, ten boys). A research diagnosis of GRD was established by an average score at or below the 25th percentile on a measure of word recognition and a measure of decoding (word identification and word attack, respectively, from the Woodcock Reading Mastery Test—revised NU; WRMT-R/NU; Woodcock, 1998; hereafter referred to as the basic reading composite). Low-achieving criteria was used to operationalize GRD because of the substantial research indicating lack of differences in deficits between children diagnosed via IQ discrepancy versus low-achieving methods (Fletcher et al., 1994). GRD participants also had to score at or below the 25th percentile on at least one of two measures of reading comprehension (i.e., Gray Oral Reading Test—Fourth Edition Comprehension; GORT-4, Wiederholt & Bryant, 2000, and Passage Comprehension from the WRMT-R/NU). On the GORT-4 comprehension subtest, participants read passages aloud and answered multiple-choice questions presented in both written and oral format. Passage comprehension requires children to read a passage silently and then verbally answer a written sentence cloze. Note that in the present study, we did not combine the reading comprehension measures into a composite score because previous research findings suggest different reading comprehension measures place demands on various cognitive processes (Cutting & Scarborough, 2006; Francis et al., 2006; Keenan et al., 2008). Twenty-two percent (n=4) of GRD participants scored at or below the 25th percentile on the GORT-4 only, 33% (n=6) scored below this cutoff on the WRMT/NU only, and 44% (n=8) scored below the 25th percentile on both comprehension measures.

Participants in the S-RCD group averaged at or above the 40th percentile on the basic reading composite despite scoring at or below the 25th percentile on one or more of two measures assessing reading comprehension, including comprehension from the GORT-4 and passage comprehension from the WRMT-R/NU. Seventeen participants were categorized in this group (14 girls, three boys). Eighty-two percent (n=14) of S-RCD participants scored at or below the 25th percentile on the GORT-4 only, 6% (n=1) scored below this cutoff on the WRMT/NU only, and 12% (n=2) scored below the 25th percentile on both comprehension measures.

Children that met criteria for the TD group scored at or above the 40th percentile on the basic reading composite and on both reading comprehension measures (GORT-4 comprehension and passage comprehension from the WRMT-R/NU). Twenty-one children fit into this group (nine girls, 12 boys).

ADHD symptomology Parent rating scales (Attention Deficit Hyperactivity Rating Scale IV—home version; DuPaul, Power, Anastopoulos, & Reid, 1998) were obtained for 54 of the 56 (96%) eligible participants. Percentiles of inattention and hyperactivity symptoms on this measure were used to establish levels of ADHD symptomology.

Measures

IQ The Wechsler Intelligence Scale for Children, Third Edition (WISC-III; Wechsler, 1991) was administered to measure overall intellectual functioning.[2]

Fluency measures Isolated word fluency was measured using the Test of Word Reading Efficiency—Sight Words and Phonemic Decoding (TOWRE; Torgesen, Wagner, & Rashotte, 1999). Contextual word fluency was measured using the GORT-4 Fluency subtest.

Oral language measures Measures of language included the Peabody Picture Vocabulary Test (PPVT-III; Dunn & Dunn, 1997) the Test of Language Development—Intermediate (TOLD-I:3, Grammatic Comprehension and Sentence Combining subtests; Newcomer & Hammill, 1997), and the Test of Language Competence—Expanded (TLC-E, Ambiguous Sentences; Making Inferences; Wiig & Secord, 1989). The PPVT-III assesses receptive vocabulary by asking participants to select the picture that best represents the meaning of the stimulus word presented orally by the examiner. The TOLD-I:3 subtests assess receptive and expressive grammar (syntax). In Sentence Combining, participants are instructed to combine two sentences into one, and in Grammatic Comprehension, participants must identify grammatically correct sentences. The subtests from the TLC-E examine alternative interpretations of sentences (ambiguous sentences) as well as listening to a scenario and deducing what may have happened (making inferences); given these demands, it is important to note that these last two measures of oral language tap types of higher level aspects of oral language that have been classified by some researchers as within the realm of executive function (Swanson & Alexander, 1997).

Executive function measures Executive function measures included the Tower of London (TOL; Shallice, 1982), Elithorn Perceptual Maze Test (Mazes; Kaplan, Fein, Kramer, Delis, & Morris, 1999), and Digit Span Backwards from the WISC-III or WISC-IV (Wechsler, 1991, 2003). The TOL is a computerized task that consists of three beads that vary in color and a board featuring three vertical pegs. Participants are shown a picture displaying the ending position of the tower to be built. The participant's task is to move the beads across the three pegs to build the target tower in a specified number of moves. The task assesses spatial planning, rule learning, and inhibition of impulsive responding. The mazes subtest requires choosing a single path that passes through circles within a "lattice" of lines in an inverted triangular structure without backtracking. This measure provides information about planning, organization, and monitoring abilities. Five TD participants, six GRD children, and six S-RCD subjects did not receive the TOL subtest, reducing the sample size for this set of analyses. To assess working memory, we calculated digit span backwards. Digit span backwards is a task requiring participants to verbally repeat a list of numbers in the reverse order from which they were originally presented by the examiner. The task requires mental manipulation of orally presented information. Digit spans range in length from two to eight digits.

Procedures

Participants attended 2 days of evaluation at the Kennedy Krieger Institute. We obtained informed consent from parents and assent from children prior to testing. We executed

[2] A subset of participants (N=8) were also tested under NIH grant R01-HD044073 and thus were administered the Wechsler Intelligence Scale for Children—Fourth Edition (WISC-IV; Wechsler, 2003).

procedures in accordance with the Johns Hopkins Medical Institutional Review Board. We determined final eligibility for participation on day 1 via ability and achievement testing. On day 2, we administered additional neuropsychological and achievement tests. Assessments were administered by staff supervised by doctoral-level faculty.

Results

Analyses consisted of four multivariate analyses of variance (MANOVAs) with group as the independent variable and with: (1) the basic descriptor variables (age, FSIQ, basic reading composite, the two reading comprehension measures, as well as the two ADHD indices, (2) the fluency measures, (3) the oral language measures, and (4) the executive function measures. Finally, to assess prediction of reading comprehension performance across groups, we conducted two hierarchical regression analyses, with the fluency, oral language, and executive function measures predicting performance on each reading comprehension measure. Because of the constructs we were examining and their potential overlaps with various aspects of cognition (e.g., the overlap between oral language and verbal IQ), we necessarily did not covary for IQ. For all analyses, a significance level of $p<0.05$ was selected. To control for type I error, univariate analyses and post hoc tests (Tukey's honestly significant difference) were used to examine group differences only when MANOVAs were significant, as indicated by Wilks' lambda.

Basic descriptor variables The MANOVA on the basic descriptor variables yielded a significant effect of group [$F(10,98)=30.54$, $p<0.0001$]. Univariate follow-up tests revealed no significant differences in age or ADHD symptomology between groups; however, statistically significant differences were present on FSIQ, basic reading composite, WRMT/NU passage comprehension, and GORT-4 passage comprehension [$F(2,56)$, all $p<0.0001$]. Post hoc pairwise tests revealed that TD children scored significantly higher than participants with GRD and S-RCD on FSIQ, WRMT/NU passage comprehension, and GORT-4 comprehension (all $p<0.0001$). As expected, TD and S-RCD students both scored higher than children with GRD on the basic reading composite ($p<0.0001$). However, S-RCD participants scored higher than the GRD group on WRMT/NU passage comprehension ($p<0.0001$), while GRD participants scored higher than S-RCD participants on GORT-4 comprehension ($p<0.001$). See Table 1 for means, significant pairwise comparisons, and effect sizes.

Fluency measures The MANOVA conducted on fluency measures (TOWRE sight word efficiency, phonemic decoding, and GORT-4 fluency) revealed a significant group difference [$F(6,102)=18.78$, $p<0.0001$]. Univariate follow-up analyses revealed significance for sight word efficiency [$F(2,56)$, $p<0.0001$], phonemic decoding ($p<0.0001$), and GORT-4 fluency ($p<0.0001$). Post hoc pairwise comparisons revealed that on both the TOWRE sight word efficiency and TOWRE phonemic decoding, TD and S-RCD participants scored similarly and significantly higher than children with GRD (both $p<0.0001$). On the Gort-4 fluency measure, however, all groups were significantly different from one another, with TD children reading more fluently than children with S-RCD who scored statistically higher than participants with GRD (all $p<0.0001$). Means, significant pairwise comparisons, and effect sizes for the reading measures are displayed in Table 2.

Because our MANOVA and hierarchical regression analyses regarding isolated versus contextual word fluency suggested some separability between these measures, we

Table 1 Means, standard deviations, significant differences, and effect sizes on basic descriptor variables

Measure	TD		S-RCD		GRD		ES	ES	ES
	M	SD	M	SD	M	SD	TD v. S-RCD	TD v. GRD	S-RCD v. GRD
Age	11.67	1.63	12.27	1.30	11.65	1.46	0.41	0.01	0.45
FSIQ	114.62	12.67*,**	93.06	14.00	94.00	11.77	1.61	1.69	−0.08
Basic reading	105.57	6.53*	102.22	5.22***	83.48	5.60	0.57	3.63	3.46
WRMT/NU Passage comprehension	111.67	9.50*,**	98.88	9.14***	86.78	5.76	1.37	3.17	1.59
GORT-4 Comprehension[a]	13.10	1.51*,**	6.47	1.66***	8.67	1.85	4.18	2.62	1.25
DuPaul inattention[b]	63.93	31.48	72.42	31.30	81.29	23.20	0.27	0.63	0.32
DuPaul hyperactivity[b]	48.06	32.98	52.12	37.58	60.43	33.88	0.11	0.37	0.23

[a] GORT-4 Comprehension score is based on a scaled score, mean=10, SD±3

[b] DuPaul Inattention and Hyperactivity scores are based on a percentile rank; all other scores are based on a standard score, mean=100, SD±15

*$p<0.05$ TD versus GRD; **$p<0.05$ TD versus S-RCD; ***$p<0.05$ GRD versus S-RCD

Table 2 Means, standard deviations, significant differences, and effect sizes on fluency measures

Measure	TD		S-RCD		GRD		ES	ES	ES
	M	SD	*M*	SD	*M*	SD	TD v. S-RCD	TD v. GRD	S-RCD v. GRD
TOWRE sight words	102.52	8.34*	101.12	8.14***	85.11	8.94	0.17	2.02	1.87
TOWRE phonemic decoding	102.81	8.78*	99.76	6.24***	77.89	8.80	0.40	2.84	2.87
GORT-4 fluency[a]	11.33	2.76*,**	8.18	2.22***	3.67	2.40	1.26	2.96	1.95

[a] GORT-4 fluency score is based on a scaled score, mean=10, SD±3; all other scores are based on a standard score, mean=100, SD±15

*$p<0.05$ TD versus GRD; **$p<0.05$ TD versus S-RCD; ***$p<0.05$ GRD versus S-RCD

investigated whether group differences on GORT-4 fluency, particularly with regard to the children with S-RCD, remained after controlling for isolated word fluency. Therefore, we conducted an analysis of covariance (ANCOVA) with group as the independent variable and GORT-4 fluency as the dependent variable and covaried for performance on our isolated word fluency measures (i.e., the TOWRE subtests). The ANCOVA was significant [$F(2,52)=9.91$, $p<0.0001$]; pairwise post hoc tests revealed that the findings were consistent with earlier analyses in which the TD children scored statistically significantly higher than both the GRD ($p=0.003$) and S-RCD ($p<0.0001$) groups.

Oral language measures The MANOVA conducted on language measures (TOLD-sentence combining, TOLD-grammatic comprehension, PPVT-III; TLC-E ambiguous sentences, TLC-E making inferences) revealed a significant group difference [$F(10,98)=3.93$, $p<0.0001$]. Univariate follow-up tests revealed significance for all measures [$F(2,56)$, all $p<0.001$] except the TOLD-sentence combining ($p=0.17$). Post hoc pairwise comparisons revealed that TD children scored significantly higher than GRD and S-RCD participants on the TLC-E ambiguous sentences ($p<0.03$), TLC-E making inferences ($p<0.004$), and PPVT-III ($p<0.001$). There was no statistically significant difference between children with S-RCD or GRD on TLC-E ambiguous sentences, TLC-E making inferences, or the PPVT-III (all $p>0.37$). On the TOLD-grammatic comprehension subtest, the TD children scored significantly higher than children with GRD ($p<0.003$), while there were no significant differences occurring between the TD and S-RCD participants ($p>0.40$) or between the S-RCD and GRD groups ($p=0.11$). Means, significant pairwise comparisons, and effect sizes for the reading measures are displayed in Table 3.

Executive function measures For the MANOVA on the executive function measures (TOL excess moves, mazes, digit span backwards), we covaried for age because of the lack of norms for the TOL; therefore, we used raw scores for all variables in the analysis. The MANCOVA revealed a significant group difference [$F(6,72)=3.13$, $p=0.01$]. Univariate follow-up tests results revealed significance for excess moves [$F(2,38)$, $p<0.001$] and mazes ($p=0.01$), but results for digit span backwards failed to reach the significance criterion [$F(2,38)$, $p=0.16$], although suggested poorer performance by children with GRD as compared to TD children (post- hoc pairwise comparison, $p=0.06$). Post hoc pairwise

Table 3 Means, standard deviations, significant differences, and effect sizes on oral language measures

Measure	TD		S-RCD		GRD		ES	ES	ES
	M	SD	*M*	SD	*M*	SD	TD v. S-RCD	TD v. GRD	S-RCD v. GRD
PPVT-III	117.81	12.89*,**	101.29	11.97	101.67	13.69	1.33	1.22	0.03
Sentence combining[a]	9.81	3.09	8.35	2.29	8.33	2.80	0.54	0.50	0.01
Grammatic comprehension[a]	11.81	1.89*	10.65	3.86	8.72	2.32	0.38	1.46	0.61
Ambiguous sentences[a]	9.90	3.13*,**	7.47	3.22	6.11	2.50	0.77	1.34	0.47
Making inferences[a]	10.24	2.34*,**	7.71	2.14	7.39	2.33	1.13	1.22	0.14

[a] Ambiguous sentences, making inferences, sentence combining, and grammatic comprehension scores are based on scaled scores, mean=10, SD±3; PPVT-III score is based on a standard score, mean=100, SD±15

*$p<0.05$ TD versus GRD; **$p<0.05$ TD versus S-RCD; ***$p<0.05$ GRD versus S-RCD

comparisons indicated that participants with S-RCD had more TOL excess moves than children with GRD (p=0.04) and TD children (p<0.001). On mazes, TD participants scored significantly higher than the children with S-RCD (p=0.004); however, no significant differences existed between GRD and S-RCD participants (p=0.16). See Table 4 for the means, significant pairwise comparisons, and effect sizes.

Analyses controlling for ADHD symptomology Even though there were no significant differences between groups on ADHD symptomology, in order examine any potential effects of ADHD symptoms, we reran all the MANOVAs using the DuPaul inattention and hyperactivity symptom percentiles as covariates. Results for these analyses revealed that all the findings remained the same (i.e., those that were previously statistically significant retained a p value of 0.05 or lower).

Prediction of reading comprehension performance To examine the contribution of fluency, oral language, and executive function to reading comprehension in a continuous manner, we conducted two hierarchical regression analyses. A correlation matrix for all variables is presented in Table 5. For the hierarchical regression analyses (summarized in Table 6), we condensed our measures to have appropriate power. We formed a composite score for the two TOWRE subtests by averaging participant scores and a composite oral language score featuring only the subtests for which we found significance, created by conducting a principal components factor analysis. In addition to these two composite scores, we also included GORT-4 fluency, mazes, and TOL in our analyses.

We entered the independent variables in the following order: TOWRE composite, GORT-4 Fluency, oral language composite, and the two executive function variables (TOL excess moves and mazes). The total amount of variance explained in the hierarchical regression with the GORT-4 was 52%, whereas it was 68% for WRMT/NU passage comprehension. Isolated and contextual word fluency, as well as the oral language composite, all made significant independent contributions to both reading comprehension measures; however, the amount of variance contributed by each step was quite different for the two regressions. For WRMT/NU passage comprehension, isolated word fluency explained 44% of the variance, contextual word fluency added an additional 14%, and oral language added an additional 9%. The executive function variables explained a non-significant 1% of the variance. With all the variables entered simultaneously in the model, oral language was the only significant predictor (p=0.003). For the GORT-4 comprehension hierarchical regression analyses, isolated word fluency explained only 12% of the variance.

Table 4 Means, standard deviations, significant differences, and effect sizes on executive function measures

Measure	TD		S-RCD		GRD		ES	ES	ES
	M	SD	*M*	SD	*M*	SD	TD v. S-RCD	TD v. GRD	S-RCD v. GRD
Mazes[a]	11.00	2.89*	6.82	3.55	8.62	3.99	1.29	0.68	0.48
TOL excess moves	21.67	14.77*	53.73	29.18**	31.77	16.93	1.39	0.64	0.92
Digit span backwards	4.44	1.34	4.00	0.78	3.62	0.96	0.40	0.70	0.43

[a] Mazes is based on a scaled score, mean=10, SD±3; TOL excess moves and digit span backwards are based on a raw score. In addition, for TOL, analyses were conducted using a transformed variable (square root) to account for unequal variances; however, data are reported using original scores

*p<0.05 TD versus S-RCD; **p<0.05 GRD versus S-RCD

Table 5 Intercorrelations among all variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
FSIQ	–	0.47[a]	0.58[a]	0.69[a]	0.39[a]	0.43[a]	0.63[a]	0.69[a]	0.33[b]	0.47[a]	0.51[a]	0.46[a]	0.64[a]	0.27[b]	−0.49[a]	−0.17	−0.06
Basic reading composite		–	0.34[b]	0.77[a]	0.65[a]	0.90[a]	0.79[a]	0.42[a]	0.13	0.49[a]	0.49[a]	0.30[b]	0.21	0.28[b]	−0.22	−0.20	−0.25
GORT-4 comprehension			–	0.54[a]	0.22	0.31[b]	0.47[a]	0.57[a]	0.23	0.28[b]	0.46[a]	0.48[a]	0.26	0.18	−0.47[a]	−0.24	−0.14
WRMT passage comp.				–	0.57[a]	0.66[a]	0.75[a]	0.54[a]	0.25	0.53[a]	0.62[a]	0.45[a]	0.37[a]	0.24	−0.37[b]	−0.17	−0.09
TOWRE sight word efficiency					–	0.69[a]	0.71[a]	0.35[a]	0.20	0.28[b]	0.24	0.17	0.25	0.33[b]	−0.17	−0.34[b]	−0.41[a]
TOWRE phonemic decoding						–	0.80[a]	0.37[a]	0.11	0.42[a]	0.42[a]	0.28[b]	0.29[b]	0.34[b]	−0.25	−0.21	−0.25
GORT-4 fluency							–	0.53[a]	0.24	0.52[a]	0.41[a]	0.42[a]	0.39[a]	0.43[a]	−0.30	−0.35[b]	−0.32[b]
PPVT-3								–	0.30[b]	0.54[a]	0.51[a]	0.44[a]	0.39[a]	0.17	−0.46[a]	−0.19	−0.18
TOLD sentence comp.									–	0.28[b]	−0.01	0.28[b]	0.28[b]	0.10	−0.25	0.12	0.03
TOLD grammatic comp.										–	0.47[a]	0.41[a]	0.35[a]	−0.01	−0.18	−0.07	0.05
TLC ambiguous sentences											–	0.28[b]	0.19	−0.01	−0.12	−0.02	0.06
TLC language comp.												–	0.28[b]	0.29[b]	−0.25	−0.23	−0.24
Mazes													–	0.22	−0.54[a]	−0.25	−0.13
Backwards digit span														–	0.34[b]	−0.35[a]	−0.42[a]
TOL excess moves															–	0.33[b]	0.27
DuPaul attention																–	0.58[a]
DuPaul hyperactivity																	–

[a] Correlation is significant at the 0.01 level (two-tailed)

[b] Correlation is significant at the 0.05 level (two-tailed)

Table 6 Hierarchical regression models predicting reading comprehension

Step and predictors entered	GORT-4 comprehension								WRMT/NU passage comprehension							
	R^2	F	p	R^2+	▲F	▲p	β	$p(\beta)$	R^2	F	p	R^2+	▲F	▲p	β	$p(\beta)$
Model 1A	0.12	5.60	0.02	0.12	5.60	0.02			0.44	32.01	0.00	0.44	32.01	0.00		
TOWRE composite							0.35	0.02							0.66	0.00
Model 1B	0.29	8.19	0.00	0.17	9.61	0.00			0.58	27.63	0.00	0.14	13.49	0.00		
TOWRE composite							−0.23	0.33							0.14	0.43
GORT-4 fluency							0.71	0.00							0.64	0.00
Model 1C	0.45	10.79	0.00	0.16	11.63	0.00			0.67	26.49	0.00	0.09	10.75	0.00		
TOWRE composite							−0.07	0.76							0.26	0.11
GORT-4 fluency							0.17	0.52							0.24	0.23
Oral language composite							0.58	0.00							0.43	0.00
Model 1D	0.52	7.99	0.00	0.07	2.53	0.09			0.68	15.97	0.00	0.01	0.73	0.49		
TOWRE composite							−0.07	0.73							0.27	0.11
GORT-4 fluency							0.58	0.57							0.24	0.25
Oral language composite							0.51	0.00							0.42	0.00
TOL excess moves							−0.28	0.05							−0.14	0.24
Mazes							−0.01	0.93							−0.07	0.57

N=46

Similar to the WRMT/NU passage comprehension, the contextual word fluency variables explained a significant amount of variance (17%); oral language explained an additional 16% of the variance. In contrast to the WRMT/NU passage comprehension, the executive function variables explained a greater amount of additional variance (7%) in this model, but did not reach conventional levels of significance ($p=0.09$); however, with all the variables entered simultaneously in the model, oral language and executive function were both significant predictors, suggesting a relatively greater contribution of executive function to the GORT-4 comprehension ($p<0.05$).

Additionally, because of the question of separability between isolated and contextual word fluency, we reran analyses reversing the order of the two; in this case, isolated word fluency no longer made a significant contribution to reading comprehension.

Discussion

In the current study, we sought to understand further the role of fluency, oral language, and executive function on reading comprehension in TD, GRD, and S-RCD readers. More specifically, we attempted to understand, within a neuropsychological framework, more about which processes are important to reading comprehension, particularly for participants with S-RCD. We were especially interested in whether bottom-up processes were largely responsible for S-RCD comprehension deficits or whether other higher-level processes appeared to play a role.

Can poor reading comprehension in children with S-RCD be explained by a processing bottleneck?

In the current study, we hypothesized that if participants with S-RCD clearly demonstrated impaired fluency despite their accurate word recognition/decoding, this finding would be evidence for weaknesses in bottom-up skills; however, evidence for this inefficiency was not found. On tasks of isolated word fluency, children with S-RCD strongly resembled the TD children; only the participants with GRD exhibited substantial weaknesses in both accuracy and speed of bottom-up processing. These findings suggest that isolated word fluency is intact in most students with S-RCD and thus cannot account for their poor reading comprehension.

When fluency was measured during text reading, rather than for isolated words, however, children with S-RCD indeed differed in comparison to the TD group. The children with S-RCD, while still performing at a higher level than participants with GRD, scored statistically significantly lower than TD children, with a group mean at about the 25th percentile (versus the 50th percentile for isolated word fluency). Whether or not this constitutes evidence for children with S-RCD showing a processing bottleneck is intertwined with the issue of the degree to which contextual word fluency is a bottom up process (i.e., whether contextual word fluency also taxes higher level processes). As will be discussed later, this pattern of differences suggests that contextual word fluency reflects other factors besides the processing speed limitations in common with isolated word fluency.

Do participants with S-RCD show weaknesses in oral language or executive function? Can the presence of ADHD symptomology explain executive function deficits, particularly (if present) for the S-RCD group?

Overall, participants with S-RCD scored lower than TD participants and similar to children with GRD on oral language measures, although they were somewhat less deficient than

GRD participants on some aspects of oral language. More specifically, both RD groups showed weaknesses in vocabulary and inferential language; however, unlike children with GRD, those with S-RCD did not show as substantial deficits on our receptive syntax measure. Of note, however, is that with somewhat younger samples of children with S-RCD featuring different measures of syntax, syntactic weaknesses have been found (Nation & Snowling, 2000); thus, further exploration of syntactic abilities in S-RCD is needed to resolve these different findings.

It is not surprising that generally, our oral language results supported the well-known fact that reading comprehension involves word-level abilities as well as oral language processes. Previous findings have documented that reading comprehension abilities likely include both syntactic and semantic skills, and our results were consistent with this viewpoint (e.g., Catts et al., 1999; Juel, 1988; McCardle et al., 2001; Nation, Adams, Bowyer-Crane, & Snowling, 1999; Nation & Snowling, 1998, 1999; Scarborough, 1990; Vellutino, Scanlon, & Tanzman, 1994). Nevertheless, some differences were found between the two RD groups. Future studies will need to investigate these differences with more sensitive measures of syntactic processing. Additionally, even though both RD groups showed similar semantic performance, this also is an area that merits further investigation, as there may be important distinctions in the type of semantic deficit in each RD group. For example, Oullette (2006) found vocabulary "depth" (semantic representations) to be a critical component in reading comprehension performance, with depth having a stronger association to reading comprehension than vocabulary "breadth" (i.e., receptive vocabulary). In his findings, he suggested that vocabulary breadth was related to phonological factors, which are less relevant to reading comprehension than vocabulary depth, which taps semantic knowledge and organization. Further exploration of syntactic and semantic skills with more sensitive measures, including measurement of breadth and depth of vocabulary as well as online syntactic processing, could provide more precise linkages to specific types of oral language deficits in children with S-RCD. Additionally, it will be important to further investigate the origin of inferential language deficits in the two RD groups. While inferential language certainly draws upon the basic oral language processes of semantics and syntax, given the higher order nature of inferential language, it may *additionally* draw upon executive functioning processes. Indeed, some have linked inferences to executive function (Swanson & Alexander, 1997) to difficulties in reading comprehension (e.g., Barnes & Dennis, 1996; Oakhill, 1993; Oakhill & Garham, 1988; Oakhill & Yuill, 1996). Given our findings of executive function deficits in the S-RCD group but less impaired syntactic performance, it will be important to examine in future studies whether the inferential language deficits in S-RCD differ in origin from those with GRD (i.e., stem more from their executive weaknesses than from their basic oral language abilities.)

The executive function findings, especially on measures of planning, organization, and monitoring, suggested a more specific deficit in this area for participants with S-RCD. Although children with GRD showed somewhat lower performance than TD children on executive function measures, children with S-RCD showed *markedly* low performance on the TOL compared to both the TD and GRD groups and lower performance than TD participants on mazes. Executive function deficits, although seen in a variety of conditions (Powell & Voeller, 2004), are well known to be associated with ADHD (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005), and studies have found that children with ADHD show deficits in higher level reading-related skills (Purvis & Tannock, 1997). Nevertheless, despite the documented relationship between executive functions and ADHD, our findings do not appear to stem from this relationship because we failed to obtain different levels of

ADHD symptoms between groups. Furthermore, in follow-up MANOVAs featuring ADHD symptoms as covariates, results remained the same as when ADHD symptoms were not accounted for. It is worthy of mention, however, that we relied exclusively on DuPaul parent ratings (i.e., mono-method, mono-trait) of their child's behavior to measure ADHD symptomology. Future studies should include a multiple-method and multiple-trait approach to symptom measurement to comprehensively investigate ADHD symptoms. Additionally, it will be critical to measure neuropsychological constructs known to be almost universally related to ADHD such as response inhibition (Barkley, 2006) to determine if the executive function weaknesses in children with S-RCD stem from deficits that are more closely linked to ADHD symptomology, or whether the executive function deficits in children with S-RCD are more reflective of higher level, ADHD symptom-independent processes.

Is there support for separation of isolated versus contextual word fluency, or does performance on these measures across and within the three groups converge?

The distinction between isolated and contextual word fluency is of particular relevance to the reading comprehension literature. In the past, there have been conflicting findings regarding the overlap between these two constructs. While often they are viewed as largely synonymous, some researchers have found that contextual word fluency uniquely predicts variance in reading comprehension above and beyond isolated word fluency, suggesting that while these constructs are interrelated, they may tap different aspects of cognition (Jenkins, Fuchs, Van den Broek, Espin & Deno, 2003a; Klauda & Guthrie, 2008). It is widely accepted in the literature that readers showing isolated word fluency deficits will most likely have contextual fluency deficits (Jenkins, Van den Broek, Espin, & Deno 2003b); however, it remains undetermined whether efficient isolated word fluency guarantees solid contextual fluency abilities.

Our results support distinctions between isolated and contextual fluency previously identified in the literature. Our TD children earned higher scores than participants with S-RCD on a measure of contextual word reading speed, whereas performances between the two groups were similar on an isolated word reading speed measure. These findings support contextual word fluency skills as being underdeveloped for children with S-RCD despite solid single word reading abilities. Participants with GRD, however, showed deficits in isolated word fluency and, not surprisingly, contextual word fluency as well.

When isolated and contextual fluency were examined across groups via hierarchical regression analyses, our results showed that the model featuring isolated word fluency entered before contextual word fluency made a unique contribution in variance (14–17%) above and beyond the other variables. Interestingly, when we reran the analyses entering context word fluency before isolated word fluency, the model was not significant. These results, taken together with our group comparisons, suggest that while isolated word fluency deficits are a sufficient cause of impaired context word fluency, isolated word fluency proficiency itself does not necessarily result in context word fluency proficiency, suggesting that contextual word fluency likely features elements of higher level cognitive processes.

Further investigation of the potential separation between isolated and contextual word fluency is necessary to determine how these concepts impact normal and impaired readers. For example, as suggested by Jenkins et al. (2003a), skilled readers likely have an automatic expectation of what word logically fits into a sentence. Children with S-RCD, however, may not be skilled at this type of prediction, which may arise from associated deficits in both language (especially semantics) and executive processes ("thinking ahead" or predicting). Such a pattern would likely result in the ability to read words in context (but not isolation) more slowly than expected, as was demonstrated by children with S-RCD in our study. To effectively measure issues of contextual versus isolated word fluency in future studies, more sensitive experimental measures should be utilized to investigate the unique and shared variance contributions of both constructs.

Do isolated and contextual word fluency, oral language, and executive function each contribute a significant amount of variance to reading comprehension? Does this contribution differ across reading comprehension measures?

For both reading comprehension measures, we observed unique contributions of isolated word fluency, contextual word fluency, and oral language to the prediction of reading comprehension and a contribution of executive function for one of the reading comprehension measures. While the percentage of unique variance for contextual word fluency after accounting for isolated word fluency was similar (14–17%) for both reading comprehension measures, as noted by other investigators previously, the amount of variance contributed by isolated word fluency and oral language varied substantially depending on the reading comprehension measure (Cutting & Scarborough, 2006; Francis et al., 2006; Keenan et al., 2008): in our study, the WRMT/NU passage comprehension drew heavily upon bottom-up skills, with isolated word fluency predicting 44% of the variance and oral language only 9%. In contrast, on the GORT-4 comprehension, isolated word fluency accounted for only 12% of the variance, while oral language accounted for 16%. Additionally, the GORT-4 comprehension measure appeared to tap executive function, specifically our planning and organization measure, more than the WRMT/NU passage comprehension did, adding approximately 7% unique variance after fluency and oral language measures and remaining one of the significant predictors of the GORT-4 comprehension when all the variables were considered simultaneously. Furthermore, it should be noted that the two RD groups varied on which comprehension measure(s) they scored poorly: 44% of the GRD group showed weaknesses only on the WRMT/NU passage comprehension, in contrast to 12% in the S-RCD group. Quite the reverse was true for the GORT-4 comprehension, with 82% of the S-RCD group showing weaknesses only on the GORT-4 comprehension in contrast to just 22% in the GRD group. In particular, these results are consistent with previous findings suggesting that the WRMT/NU comprehension relies heavily on word-level processes (hence the high rate of poor performance on this measure for the GRD group and not the S-RCD group; Keenan et al., 2008). Findings also suggest that in addition to differences in demands on bottom-up skills, the taxing of higher level skills, including both oral language and executive function, differs across measures. In particular, reading comprehension measures may vary significantly in their executive demands. This suggests that it may be important to examine not only a reader's executive function abilities but also the executive function demands in the text itself.

Summary and implications

Subsequent studies that investigate reading comprehension in TD, GRD, and S-RCD participants are needed with more fine-grained fluency and oral language components and a broader array of executive function measures. Additionally, it will be important to confirm the linkages between executive function and various aspects of higher level comprehension processes. Although many traditional reading comprehension studies do not typically classify aspects of reading comprehension under the executive function rubric, the cognitive demands of these higher level skills would reasonably suggest linkages to executive function. Our results are consistent with this viewpoint. Nevertheless, we did not directly measure meta-cognitive skills that are often assessed in reading comprehension studies, so it will be important for future studies to evaluate these linkages. Understanding how well researched higher level/meta-cognitive processes are linked neuropsychologically to executive function will be highly beneficial in terms of furthering our understanding of brain–behavior relationships underlying reading comprehension. This is particularly important for older readers because executive processing continues to develop through adolescence (Asato, Sweeney, & Luna, 2006), and potential implications of poor executive skills on reading comprehension in older children may be noteworthy. Such an approach will allow for a deeper understanding of the brain–behavior bases of impaired and skilled reading comprehension in various types of readers.

Neuroimaging data would also be particularly valuable in determining patterns of activation and brain mechanisms underlying reading comprehension deficits in different types of readers. Other considerations for future studies will be to incorporate an expanded group of working memory measures (both verbal and visual); surprisingly, we did not find substantial differences between groups on our verbal working memory measure despite previous findings suggesting children with S-RCD show deficits in verbal working memory. However, our measure may not have been sensitive enough to detect differences in working memory. Additionally, although we did not find significant differences between groups on ADHD symptoms, more comprehensive measures of ADHD (both questionnaires/ratings scales and neuropsychological measures of inhibition) are needed to fully investigate this issue. Finally, given the differences that we and others have found between reading comprehension measures, it will be important for future investigations of S-RCD to consider the manner in which S-RCD is defined (e.g., require low performance on two or more reading comprehension measures).

In summary, our study of TD, GRD, and S-RCD readers revealed that there appears to be particularly notable deficits in executive function associated with S-RCD. Additionally, our findings suggest that above and beyond fluency and oral language, executive processes may play a significant role in reading comprehension. Understanding the role of these various processes (including distinctions between different types of fluency and potential linkages between inferential language and executive function) in different reader types may help reveal more about the underlying neurobiological origins of reading comprehension success and failure beyond the single word level.

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