DESCRIBING THE COGNITIVE CHARACTERISTICS OF READING DISABILITY SUBTYPES

By

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To my parents Mary and Stephen Kearns and to my sisters, Shannon and Cabrie Kearns,

for everything… a family like ours is a rare and wonderful thing

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CHAPTER I

INTRODUCTION

There is considerable evidence that the reading problems of many young children can be prevented (e.g., Ball & Blachman, 1991; Bradley & Bryant, 1983; Byrne & Fielding-Barnsley, 1991, 1993, 1995; Cunningham, 1990; Lovett et al., 1994; Torgesen et al., 1999; Foorman et al., 1998). In even the most successful intervention studies, however, some students do not respond (e.g., Al Otaiba & Fuchs, 2006; Brown & Felton, 1990; McMaster, Fuchs, Fuchs, & Compton, 2005; Vellutino et al., 1996). A review of the literature by Al Otaiba and Fuchs (2002) found that between 8% and 80% of students failed to respond to various interventions, and Torgesen (2000) reported that more than 30% of at-risk students may not respond. Moreover, many children continue to be unresponsive when interventions are very intensive (e.g., Foorman et al., 1998; Torgesen et al., 1999; Vaughn, Linan-Thompson, & Hickman, 2003), or when students have received multiple tiers of evidence-based intervention over many hours in small groups (e.g., Wexler, Vaughn, Roberts, & Denton, 2010).

Results from this research raise the question whether these students have reached an academic asymptote. Certainly, this is possible. As Francis et al. (1996) showed in their test of the developmental lag theory, students with reading problems not only lag their peers (Stanovich, Nathan, & Vala-Rossi, 1986), they often never catch up. Evidence from the just mentioned interventions (e.g., Foorman et al., 1998; Torgesen et al., 1999; Wexler et al., 2010) suggests that students have immutable limitations. Nevertheless, we see an alternative interpretation: Academic interventions *as currently defined* may have reached their potential for helping nonresponders, but the students themselves may be a different matter. Perhaps with the right type of intervention, these low-performing students will show accelerated achievement. One possibility is to provide intervention focusing on the cognitive deficits associated with students' reading problems, for example, providing working memory training if working memory problems appear closely related to reading performance (cf. Fiorello, Hale, & Snyder, 2006; see Holmes, Gathercole, & Dunning, 2009; Klingberg et al., 2005).

The idea of designing interventions to improve students' cognitive weaknesses is appealing in principle as a different way to address an entrenched academic problem. Yet, the research on improving academic problems by cognitive intervention has a checkered history, dating from attempts in the 1960s that were based on the Illinois Test of Psycholinguistic Abilities (Kirk & McCarthy, 1961). After a series of reviews in subsequent decades showed these interventions had little value (e.g., Arter & Jenkins, 1979; Hammill & Larsen, 1974; Kavale, 1982), similarly cognitively-focused efforts dwindled, and the few studies conducted were largely ignored. Moreover, few more recently conducted cognitive intervention studies have produced encouraging effects, and none has used appropriately rigorous designs to warrant strong recommendation (Kearns & Fuchs, submitted).

Nevertheless, we question whether more treatment time and smaller instructional groups, as Vaughn and Linan-Thompson (2003) recommended, will markedly change the trajectories of nonresponsive students. We look favorably on research efforts to develop interventions with a cognitive emphasis, even as we acknowledge that the evidence right now for these is inconclusive and believe their adoption is premature.

One way to improve evidence for—and reduce skepticism about—cognitively-focused interventions is to target cognitive processes closely linked to academic performance. This has been done before with success. Phonological processing deficits cause reading problems (Snowling, 2000; Stanovich, 1988), and phonological awareness training to improve this cognitive process can improve reading performance, even without explicit reading practice (e.g., Bradley & Bryant, 1983; Byrne & Fielding-Barnsley, 1991, 1993, 1995; Cunningham, 1990). The goal, then, of our research is to find other cognitive processes that are associated with academic performance, with the ultimate goal of developing innovative and powerful interventions based on them.

In the present study, therefore, we explored possible cognitive differences among students with reading disability (RD), students with RD and either math disability (MD) or attention-deficit/hyperactivity disorder (ADHD), and typical achievement. We operationalized RD in terms of word reading or reading comprehension below the 16th percentile. We did not require a discrepancy between IQ and reading achievement because the validity of the discrepancy is questionable (e.g., Donovan & Cross, 2002; Francis, Fletcher, Shaywitz, Shaywitz, & Rourke, 1996; Francis et al., 1995; Francis et al., 2005; Fuchs, Mock, Morgan, & Young, 2003; Stanovich, 2005), and some studies suggest that students with and without a discrepancy exhibit similar cognitive difficulties (e.g., Fletcher et al., 1994; Hoskyn & Swanson, 2000; Stanovich & Siegel, 1994; Stuebing et al., 2002; but see Fuchs & Young, 2006 and Fuchs, Fuchs, Mathes, & Lipsey for a different view). However, we did set a minimum IQ requirement to separate our sample from one including students with intellectual disabilities.

We also examined differences in the reading profiles of these students. The reading construct is complex and can be measured in a variety of ways, including word reading, pseudoword reading, fluency, and reading comprehension. Performance of student groups may vary by reading measure, but comparisons of students with RD and several comorbidities are infrequent in the literature. We hope to better understand whether certain aspects of reading are most difficult for each RD subtype or whether all dimensions of reading are uniformly difficult.

We have seven research foci. The first four questions consider the cognitive profiles. For our first and second questions, we contrast the cognitive performance of those with RD to those with typical achievement (TA, operationalized by word reading and comprehension scores above the 34th percentile). Our first question is this: Are students with RD more impaired on cognitive measures than those with TA? While students with RD are clearly impaired on reading skills, it is not clear to what extent they are impaired on cognitive skills. If students with RD have a broad range of cognitive difficulties, it may suggest that remediating their reading difficulties will be more challenging because their cognitive challenges are pervasive. Our second question: Do students with RD have areas of relative strength and weakness compared to those with TA? If we find them, areas of strength and weakness in students with RD may be useful in designing intervention. If, on the other hand, those with TA are cognitively stronger across the board—that is, those with RD have no domains of relative strength and weakness, as Fletcher et al. (1994) found—we would consider our results to suggest that intensive academic work may be the only route to improvement.

We then compare RD subtypes. We ask: Are students with RD generally less impaired on cognitive measures than students with RD+MD, RD+ADHD, or RD+MD+ADHD? Like our first research question, this question allows us to determine whether students with comorbidities might have a broad range of cognitive deficits that might make learning generally harder for them than their peers with RD-only. Fourth, we ask: Are there cognitive strengths and weaknesses among students with these four subtypes? If we find differences, it might lead us to consider different forms of intervention for students with different subtypes.

Our fifth, sixth, and seventh questions concern the differential reading performance of students with different forms of RD. Our fifth question parallels the second. We ask: Do students with RD have a different pattern of reading performance than students with TA? This question allows us to understand whether certain aspects of reading present particular challenges for or may be easier for students with RD. Sixth, we ask: Do those with RD, RD+ADHD, RD+MD, and RD+MD+ADHD differ in their overall level of reading ability? We hope to better understand whether students with RD and comorbidities are generally needier than those with RD alone. Finally, our seventh research question examines whether reading performance differs by type of reading task across the RD subtypes. This may help us understand which aspects of reading require more intensive support for which types of students.

In the chapter that follows, we review the literature relevant to our research questions. To shed light on the degree of overall cognitive impairment in students with

RD and to explore whether students with RD have different patterns of strengths and weaknesses compared to those with TA, we examine the literature on the cognitive processes associated with RD. We also consider which aspects of reading may be particularly challenging for students with RD, relative to those with TA. Then, we explore what is known about the performance of students with RD-only and those with comorbid disorders (RD+MD and RD+ADHD) on cognitive measures, both for their overall performance and their patterns of strength and weakness. Finally, we consider whether different levels or patterns of reading performance might be expected across subtypes.

CHAPTER II

LITERATURE REVIEW

Cognitive Processes Associated with RD

Cognitive correlates of word reading difficulty—which comprise the majority of RD cases (Catts, Hogan, & Fey, 2003)—have been studied extensively. Word reading difficulty is caused by a phonological deficit, encompassing difficulties with phonological awareness, speeded lexical retrieval, and verbal short-term memory (Rack, Snowling, & Olson, 1992; Vellutino, Fletcher, Snowling, & Scanlon, 2004; Wagner & Torgesen, 1997). Phonological awareness is a meta-linguistic process requiring manipulation of phonological units (Castles & Coltheart, 2004; Goswami, 2000; Hulme, Snowling, Caravolas, & Carroll, 2005; Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996; Wagner & Torgesen, 1987). Children with RD use their phonological awareness to read but less skillfully than peers with TA (Price, Wise, & Frackowiak, 1995; Pugh et al., 2000; Rack et al., 1992; Ramus & Szenkovits, 2009; Shaywitz et al., 2002). Another cognitive correlate of RD is the inability to retrieve lexical information quickly (Catts, Gillespie, Leonard, Kail, & Miller, 2001; Denckla & Rudel, 1976; Manis, Doi, & Bhadha, 2000; Wolf & Bowers, 1999), although this deficit is rarely found in the absence of phonological difficulty (Compton, DeFries, & Olson, 2001; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002; Morris et al., 1998; Vukovic & Siegel, 2006).

A third source of word reading difficulty is verbal short-term memory, part of the working memory system under Baddeley and Hitch's (1974) multi-component model. Verbal short-term memory is represented by the phonological loop, which stores verbal input and rehearses it to retain storage. The working memory system also includes a visuospatial sketchpad that retains visual and spatial short-term memories, and a superordinate central executive system that regulates the prior processes, manages attention, and retrieves long-term memories (Baddeley, 2003; Baddeley & Hitch, 1974; Pickering, 2006). Researchers have found that verbal short-term memory performance contributes unique variance to the prediction of word reading skill, even when controlling for phonological awareness or naming speed (de Jong, 1998; Fletcher, 1985; Ramus & Szenkovits, 2009; Swanson & Howell, 2001), but always in addition to phonological awareness (Morris et al., 1998). Some evidence suggests that central executive processes, called executive function, also play a role in reading disability separate from verbal short-term memory (de Jong, 1998; Siegel & Ryan, 1989; Swanson & Howell, 2001).

The cognitive processes involved in reading comprehension comprise those involved in word reading (Gottardo, Stanovich, & Siegel, 1996; Juel, Griffith, & Gough, 1986; Swanson, Trainin, Necoechea, & Hammill, 2003), although the relationship between phonological processing and comprehension may be mediated through word reading (Cain, Oakhill, & Bryant, 2000; Nation, 2005; Stothard & Hulme, 1996). Working memory (Cain et al., 2000; Swanson & Alexander, 1997; Yuill, Oakhill, & Parkin, 1989), language ability (Cain & Oakhill, 2006; Nation, Clarke, Marshall, & Durand, 2004), and verbal reasoning (Cain & Oakhill, 2006; Stothard & Hulme, 1996) may link directly to comprehension performance.

Comorbidity

Comorbidity—the co-occurrence of multiple disorders—is frequent in those with RD for MD and ADHD (Butterworth, 2005; Pennington, 2006). Distinguishing students with RD-only from those with comorbid disorders is advantageous because it reduces group heterogeneity and may allow us to determine the cognitive processes relevant for each subtype (e.g., what is important for RD+ADHD but not RD-only; Pennington, Willcutt, & Rhee, 2005). We examine the literature to describe what is known relevant to our third and fourth research questions (i.e., whether those with comorbid disorders are generally more impaired than those with RD-only, and whether the pattern of strengths and weaknesses is different across these subtypes). To answer our questions regarding reading performance, we also consider overall reading level and areas of reading strength and weakness for those with comorbidities relative to those with RD-only.

Comorbidity of RD and MD

RD and MD are often comorbid (Badian, 1999; Butterworth, 2005; von Aster & Shalev, 2007) but the cognitive processes underlying each may be specific to the reading or math domain. Those with RD+MD, consequently, may exhibit additional cognitive deficits relative to those with RD-only.

Verbal short-term memory may relate to RD and not MD (Landerl, Fussenegger, Moll, & Willburger, 2009, Schuhardt, Maehler, & Hasselhorn, 2008), while visuospatial working memory may link to MD but not RD (Andersson, 2010; Schuhardt et al., 2008;

van der Sluis, van der Leij, & de Jong, 2005). So, those with RD-only may exhibit only verbal short-term memory problems and are less likely to be impaired on visuospatial short-term memory as well, although there is considerable debate whether such clear distinctions can be drawn given a fair amount of contradictory evidence (cf. Bull, Johnson, & Roy, 1999; Butterworth, 2005; McLean & Hitch, 1999; Passolunghi, Vercelloni, & Schadee, 2007; Schuchardt et al., 2008; Swanson, 1993; Temple & Sherwood, 2002). For processing speed, deficits related to RD and MD may also be different, such that speed of lexical retrieval is important in RD but nonverbal processing speed in MD (Andersson & Lyxell, 2007; McLean & Hitch, 1999; Hitch & McAuley, 1991; Willburger, Fussenegger, Moll, Wood, & Landerl, 2008).

Both MD and RD appear to involve executive function deficits (Cooney & Swanson, 1990; Fuchs et al., 2005; Passolunghi & Siegel, 2001; Siegel & Ryan, 1989; Swanson & Beebe-Frankenberger, 2004), although researchers use different tasks with different demands (i.e., verbal or nonverbal processing), which may obfuscate the true role of executive processes (Andersoon & Lyxell, 2007; Rubinsten & Henik, 2006; Rousselle & Noel, 2007; Siegel & Ryan, 1989; van der Sluis et al., 2005). The role of phonological processes in MD is less clear (cf. Jordan, Hanich, & Kaplan, 2003; Landerl et al., 2009; Simmons & Singleton, 2007), but many scholars have identified a role for it (e.g., Bull & Johnston, 1997; Dehaene & Cohen, 1997; Dehaene, Molko, Cohen, & Wilson, 2004; Fuchs et al., 2006; Hecht, Torgesen, Wagner, & Rashotte, 2001; Leather & Henry, 1994). Some have argued (e.g., Andersson & Lyxell, 2007; Geary & Hoard, 2001), however, that executive function mediates the relation between MD and phonological processing.

Comorbidity of RD and ADHD

Like RD and MD, RD and ADHD are also often comorbid (Semrud-Clikeman et al., 1992; Willcutt & Pennington, 2000). The cognitive correlates of RD and ADHD are distinct, RD defined primarily by phonological processing problems and ADHD by executive function problems (de Jong et al., 2009; Douglas & Benezra, 1990; Pennington, Groisser, & Welch, 1993; Roodenrys, Koloski, & Grainger, 2001; Willcutt et al., 2001). Students with RD-only can, however, also exhibit executive function problems (Purvis & Tannock, 2000; Roodenrys et al., 2001; Willcutt et al., 2005) In addition, individuals with RD+ADHD, similar to those with RD+MD, tend to have deficits across domains related to both disabilities, but the individual deficits are not generally more pronounced (e.g., de Jong et al., 2009; Kibby & Cohen, 2008; Purvis & Tannock, 2000).

Summary

Studies of RD and RD+MD and RD+ADHD suggest areas of difference and overlap by domain. RD is generally linked to phonological deficits, including ones in verbal working memory and speed of lexical retrieval. When RD involves reading comprehension, language and verbal reasoning may also play a role. This suggests that those with RD may have different patterns of cognitive strength and weakness than their peers with TA. It may also suggest that students with RD will have lower cognitive performance overall than their TA peers. In RD+MD, nonverbal cognitive processes may play a role they do not play in those with RD-only, suggesting both distinct strengths and weaknesses as well as possible overall lower cognitive performance in students with both disabilities. But, in areas like executive function and phonological processing, researchers have found both students with RD-only and RD+MD have difficulty. In RD+ADHD, executive function is a key process, but it does not appear to express itself in a more extreme way than in RD-only, suggesting that both for overall cognitive function and patterns of strength and weakness, no differences will appear based on ADHD.

Purpose of Study

The present study is designed to shed further light on several issues discussed but not resolved in the literature, with an ultimate goal of identifying cognitive processes that might be exploited to better target instruction for struggling readers. We also hope to better understand what academic tasks will be more and less challenging for students with RD and its comorbidities.

Cognitive research questions and hypotheses

We consider first whether individuals with RD are generally more impaired on cognitive measures than their peers with TA. We hypothesize that students with RD have overall lower cognitive performance. Some students with RD have cognitive deficits outside the phonological domain (e.g., in lexical retrieval speed, verbal short-term memory, or executive function), and this lower performance suppresses the overall cognitive level of those with RD. However, we also hypothesize that there will be areas of particular strength and weakness for those with RD because phonological awareness is such a salient deficit. We expect phonological awareness to be especially impaired (Stanovich, 1988), but other cognitive deficits may not be present in all students with RD.

Then, in comparing the RD subtypes, we ask whether the overall level of cognitive performance differs according to RD subtype. The literature does not provide evidence for a clear hypothesis. Students with RD+MD exhibit phonological processing and executive function difficulties like their RD-only peers, but the literature does not suggest either of these difficulties is likely to be more extreme than if they had RD-only (e.g., Schuhardt et al., 2008). However, students with RD+MD likely have additional cognitive deficits, potentially in nonverbal short-term memory and processing speed, so we hypothesize that those with RD-only will have higher cognitive performance than those with RD+MD and RD+MD+ADHD. But, given the isolation of ADHD in the executive function domain and the absence of evidence that these weaknesses are more extreme in ADHD (e.g., Nigg, Hinshaw, Carte, & Treuting, 1998; Roodenrys et al., 2001; Willcutt et al., 2001), we hypothesize that those with RD+ADHD will have similar cognitive levels as those with RD-only, and RD+MD+ADHD as those with RD+MD. To our fourth research question, whether there are differential patterns of strength and weakness, the research evidence just mentioned suggests the likelihood of differential patterns between RD-only and RD+MD, but no such patterns for ADHD.

Academic research questions and hypotheses

For the question of differential performance by reading measure for RD versus TA, the phonological focus of RD suggests that those with RD will do worse on tasks requiring strong phonological awareness. In particular, pseudoword reading relies on phonological awareness combined with grapheme-phoneme correspondence knowledge, so performance of students with RD may be weaker than for other measures where semantics and long-term memory can be used. We hypothesize, therefore, a non-uniform pattern of strengths and weaknesses across measures for RD versus TA.

For the comparison of the RD subtypes, it is difficult to say whether those with comorbidities are likely to be generally more impaired. It is not clear what effect comorbidities might have on, for example, fluency or comprehension tasks, relative to word reading tasks. Nor is it clear whether a differential pattern across measures would be found. For the last two research questions, therefore, we do not have established hypotheses.

CHAPTER III

METHODS

Participants

We selected the sample in two phases, first to identify students with RD and second identify students with TA.

Participants with reading disability

To identify students with RD, we contacted principals of elementary schools in the Metropolitan Nashville Public Schools. We asked for permission to speak with special education teachers who worked with students with RD, as well as reading specialists and teachers who taught remedial reading classes. Forty-eight teachers agreed to work with us, 41 special educators working with students with RD, 1 reading specialist, and 6 teachers of remedial reading classes. These teachers were from 40 of the 75 district elementary schools reflecting the community's socioeconomic diversity (e.g., number of students receiving free/reduced-price lunch; sample: M = 74%; district: M = 72%).

We asked these teachers to identify students meeting the following criteria: presence of serious reading problems, absence of intellectual disabilities, absence of emotional or behavior disorders, absence of autism-spectrum disorder, and no identification as an English Learner. Teachers identified students they believed met these criteria, and we screened 357 of them to ensure that they met our definitions of serious reading problems and absence of intellectual disabilities (see Table 1).

Table 1. Students in study by teacher designation and inclusion criteria

	Teacher Designation					
	RD (*n* = 354)			TA (*n* = 179)		
Inclusion criteria met	Criterion	IQ met [a]	IQ not met	Criterion	IQ met [a]	IQ not met
TOWRE-PD / TOWRE-SW	< 16%ile	53	0	>35%ile	43	0
WJ3-PC	< 16%ile	29	2	>35%ile	9	0
TOWRE + WJ3-PC	< 16%ile	170	10	>35%ile	109	0
No criteria	> 16%ile	89	1	>35%ile	18	0

Note: TOWRE = Test of Word Reading Efficiency, score on either the Sight Word Efficiency or the Phonemic Decoding Efficiency subtest; WJ3-PC = Woodcock -Johnson Test of Achievement, 3rd Edition, Passage Comprehension subtest; RD = Reading disability; TA = Typically achieving. *a* IQ criterion was a *T* score of 30 or greater on either the Wechsler Abbreviated Scale of Intelligence Vocabulary or Matrix Reasoning subtest.

Our definitions were based on the use of standard scores or *T* scores normed on the performance of a population-representative sample (see Table 2 for score cutoffs based on our definitions).

Table 2. Cut points for inclusion criteria

	Score type	Disability			Typical achievement		
		Score	%ile	SDs	Score	%ile	SDs
Reading :							
TOWRE-PDE/SWE	SS	< 86	< 16	–1	> 89	> 24	–0.5
			or			and	
WJ3-PC	SS	< 86	< 16	–1	> 89	> 24	–0.5
Mathematics:							
WRAT-A	SS	< 86	< 16	–1	> 89	> 24	–0.5
			or			and	
KM-PS	SS	< 86	< 16	–1	> 89	> 24	–0.5
Attention: Conners'	TS	> 64	> 94	+1.5	< 65	< 93	+1.5
IQ: WASI							
Vocabulary	TS	> 30	> 2	–2	> 30	> 2	–2
			or			and	
Matrix Reasoning	TS	> 30	> 2	–2	> 30	> 2	–2

Note: Score type SS = standard score (*M* = 100, *SD* = 15; TS = *T*-score (*M* = 50, *SD* = 10). SDs = Standard deviations from score mean for cutoff score. TOWRE-PDE = Test of Word Reading Efficiency, Phonemic Decoding Efficiency subtest; SWE = Sight Word Efficiency subtest. WJ3-PC = Woodcock-Johnson-III Tests of Achievement, Passage Comprehension subtest. WRAT-A = Wide Range Achievement Test, Third Edition, Arithmetic subtest; KM-PS = Key Math, Revised, Problem Solving subtest; Conners' = Conners' Teacher Rating Scale, short form; higher scores indicate more attention difficulties. WASI = Wechsler Abbreviated Scale of Intelligence.

Standard scores and *T* scores are provided by test publishers based on normative data but different scales (standard scores, *M* = 100; *SD* =15; *T* scores, *M* = 50, *SD* = 10). The IQ cutoff was the same for all students. All students had to have a *T* score greater than 30 (at or above the 3rd percentile) on either the Wechsler Abbreviated Scale of Intelligence Vocabulary or Matrix Reasoning subtest (we describe all screening tests in more detail in the following section). A few students did not meet the IQ criterion (see “IQ not met” column of Table 1).

For RD, MD, and ADHD identification, we used the following criteria. Students received an RD designation if either of their Test of Word Reading Efficiency (Phonemic

Decoding Efficiency subtest or Sight Word Efficiency subtest) standard scores *or* their Woodcock Johnson III, Reading Comprehension subtest standard score was 85 or lower. Students were designated MD if their standard score on the Wide Range Achievement Test, Arithmetic subtest was 85 or lower or their standard score on the Key Math-Revised Problem Solving subtest was 85 or lower. The RD and MD score cutoffs meant that students with those designations scored at the 15th percentile or lower, at least 1 *SD* below the standardization sample mean on the screening measures. Students were designated ADHD if their Conners' Teacher Rating Scale, Short Form *T* score was 65 or higher. Higher scores indicate more attention problems. The ADHD cutoff meant that students with an ADHD designation were rated at the 94th percentile or higher, more than 1.5 *SD*s above the standardization sample mean. This cut score was used because the Conners' manual (Conners, 1997) recommended it for designating students ADHD. See Table 2 for descriptions of the cutoffs.

Of the 354 students screened, 252 students met our criteria for reading problems and our IQ criterion. Eighty-nine students did not have reading achievement below our criterion, and 13 students had IQ scores below our cutoff (see Table 1). Of those 252 who met at least one reading criterion and the IQ criterion, 53 students met only the Test of Sight Word Efficiency reading criterion, 29 met only the Woodcock-Johnson Passage Comprehension criterion, and 170 met both. Twenty-one students could not complete all testing sessions, and teachers did not complete the Conners' Rating Scales necessary to identify ADHD for 19 students. The final sample of students with RD therefore includes 212 children.

Participants with typical achievement (TA)

For TA identification, students had to have TOWRE, WJ3-PC, and WRAT3-A standard scores of 94 or greater. These cutoffs meant that all students in the TA sample had scores on all academic tests at the 35th percentile or higher, no more than 0.4 *SD*s below the standardization sample mean. They also had to have a Conners' *T*-score of 64 or lower, meaning a rating at the 93rd percentile or lower, less than 1.5 *SD*s above the mean.

For the sample of students with TA, we worked with 16 general education teachers at 4 of the 40 schools in which we had screened students with RD. We selected schools across the distribution of free/reduced-price lunch for the entire school district. To do this, we first excluded the four schools with the highest free/reduced-price lunch percentages and four schools with the lowest percentages from the TA sample. We then divided the remaining schools into three free/reduced-price lunch bands and selected at least one school from each band.

Within the four selected schools, we asked the teachers to identify students across the range of achievement, excluding only those with ADHD or ADD, emotional or behavior disorders, autism-spectrum disorder, or identification as an English Learner. We did not give teachers specific instructions for eliminating low-performing students because we wanted to sample the range of student abilities. We screened 191 students for the sample of students with TA. To be included in the study, TA students had to have achievement at or above the 35^{th} percentile for speeded word reading, pseudoword reading, reading comprehension, arithmetic skill, and mathematical problem solving skill. These students also had to have IQ scores no more than 2 SDs below the standard score mean and Conners' ADHD ratings less than 2 SDs above the *T* score mean. Of the 179 students screened for TA, 109 met all reading screening criteria. These students were administered the Wide Range Achievement Test, Arithmetic subtest to screen for typical achievement on arithmetic calculation. We decided to screen for typical achievement on problem solving after selecting some students as TA, so 85 students were administered the problem solving screening measure, the Key Math-Revised Problem Solving subtest. Seventy-one students met both mathematics criteria. Only 51 students met both reading and mathematics criteria.

Demographic data for the final RD (n = 212) and TA (n = 51) samples are presented in Table 3. There were no statistically significant differences between the students with TA and RD on gender, grade, or socioeconomic status, measured by whether students received free or reduced-price lunch. There were, however, differences on race (χ^2 [3] = 10.48, p = .02), with the sample of RD students having a larger proportion of African-American students than the TA sample.

Table 3. Demographic data for students with RD and typical achievement

	Student Data by Achievement Status									
	RD-identified (*n* = 212)				TA-identified (*n* = 51)					
Variable	*M*	*SD*	*n*	*(%)*	*M*	*SD*	*n*	*(%)*	F^a	X^2
Gender										0.15
Male			131	61.8			30	58.8		
Female			81	38.2			21	41.2		
Grade										0.82
2nd			53	25			14	27.5		
3rd			59	26.6			11	21.6		
4th			100	47.9			26	51		
Race										10.48 *
Black			120	56.6			18	35.3		
White			66	31.1			19	37.3		
Hispanic			19	9.0			11	21.6		
Other			7	3.8			3	5.9		
FRL status	74.44	20.7			74.44	12.68			0.01	

Note: FRL = Free or reduced-price lunch; RD = Reading disability; TA = typical achievement. *a* Degrees of freedom for *F* = 1, 281. * = Chi square is significant at $p < .05$ level.

Measures

Screening measures

We first tested to be sure students met our IQ, reading, and math inclusion criteria. Students' scores on these measures are reported in Table 5. We measured IQ using the Wechsler Abbreviated Scale of Intelligence (WASI, Wechsler, 1999) using the two subtest form with Vocabulary and Matrix Reasoning subtests. The WASI has an alpha reliability of .96 and a test-retest reliability of .92. Our reading measures for screening were the Test of Word Reading Efficiency (Torgesen, Wagner, & Rashotte, 1999), Phonemic Decoding (TOWRE-PD) and Sight Word (TOWRE-SW) subtests. The former requires examinees to read as many pseudowords as possible in 45 seconds, while the latter requires them to read real words with the same time limit. The TOWRE-PD has alternate-form reliability of .94 and the TOWRE-SW has alternate-form reliability of .93.

Table 5. Scores on screening measures for disability categories.

	TA	RD-only	RD+MD	RD+ADHD	RD+MD+ADHD
n	51	47	105	13	47
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
WASI-MR[a]	54.59 (6.90)	46.40 (11.65)	40.68 (10.56)	43.69 (9.38)	39.21 (10.32)
WASI-V[a]	53.02 (8.61)	42.36 (7.21)	37.25 (8.14)	36.54 (7.29)	37.40 (8.75)
TOWRE[b]	108.51 (11.49)	76.94 (7.03)	73.90 (11.04)	80.69 (10.50)	71.85 (9.68)
WJ3-PC[b]	104.61 (7.36)	81.85 (7.79)	77.68 (10.56)	81.85 (4.95)	77.79 (11.05)
WRAT3-A[b]	108.67 (7.97)	94.60 (8.00)	78.26 (10.06)	92.85 (5.34)	76.74 (11.19)
KMR-PS[b]	106.67 (9.09)	96.49 (7.44)	86.14 (8.50)	93.85 (3.63)	83.85 (7.68)
Conners[a]	48.12 (6.09)	51.89 (6.63)	53.65 (7.02)	70.31 (4.92)	73.23 (7.33)

Note: Standard deviations given in parentheses. RD = Reading disability; MD = Math disability; ADHD = Attention-deficit/hyperactivity disorder. WASI-MR = Wechsler Abbreviated Scale of Intelligence, Matrix Reasoning subtest; WASI-V = Wechsler Abbreviated Scale of Intelligence, Vocabulary subtest; TOWRE = Test of Word Reading Efficency; WJ3-PC = Woodcock-Johnson III Test of Achievement, Passage Comprehension subtest; WRAT-A = Wide Range Achievement Test III, Arithmetic subtest; KMR-PS = Key Math, Revised, Problem Solving subtest; Conners = Conners Teacher Rating Scale, Short Form.

[a] Scores are *T* scores based on normative data, with *M* = 50 and *SD* = 10.

[b] Scores are standard scores based on normative data, with *M* = 100 and *SD* = 15.

For reading comprehension, we tested students on the Woodcock-Johnson III Tests of Achievement, Passage Comprehension subtest (WJ3-PC; Woodcock, McGrew, & Mather, 2001), a cloze-based test of sentence and passage comprehension requiring students to add a single word to sentences. The test-retest reliability for the WJ3-PC subtest is .91. For this test, we adjusted the ceiling rules in two ways. First, the test has a ceiling of 6 consecutive incorrect items which we reduced to 5 items. Second, standard administration requires examiners to test by complete page, which means that examinees may be required to reach a ceiling of 9 consecutive incorrect items, but we eliminated this requirement and kept a strict 5-item ceiling. We made these adjustments because, after the first few days of testing, we found that students with RD became agitated when forced to complete large numbers of difficult items. Our application of these changes was the same for students with RD and typical achievement.

We also used the WJ3-PC standard scores for screening despite making this change. If the change had any effect, it would be to artificially deflate scores and result in RD students entering the study without really meeting RD criteria. This is a concern for those 27 students with RD who entered the study only by virtue of their WJ3-PC scores (see Table 1); 9 of these 27 did have standard scores of exactly 85 (M = 82.35, SD = 2.67). But the standard scores for these students for the reading comprehension measure administered later (the WIAT2-RC) were actually much lower (M = 74.78, SD = 9.97), while the students with TA performed similarly on both (WJ3-PC: M = 104.50, SD = 7.34; WIAT2-RC: 104.71, SD = 7.33). Given that the WIAT2-RC results suggest these students fit our criteria, the students who entered the study based on the WJ3-PC alone can be considered RD even using the standard scores under the adjusted WJ3-PC ceiling procedure.

We measured arithmetic ability using the Wide Range Achievement Test, Version III, Arithmetic (WRAT3-A; Wilkinson, 1993) subtest. The WRAT3-A has a .89 alternate form reliability. The WRAT3-A comprises arithmetic items of increasing difficulty, beginning with simple calculation but advancing to multiple-digit computation and advanced skills like fractions and decimals. Students were administered the Key Math-Revised Problem Solving (KMR-PS, Connolly, 1988) subtest, in which they orally responded to aurally presented math problems. The split-half reliabilities of the KMR-PS for spring administration are .74, .79, and .91 respectively for Grades 2, 3, and 4, with an alternate form reliability of .67.

Session 1 measures

Students first completed the Wechsler Individual Achievement Tests II, Reading Comprehension subtest (WIAT2-RC; Psychological Corporation, 2005), a silent reading comprehension test allowing free-response answers to questions about sentences and passages. The WIAT2-RC is a grade-based test, but it has a reversal rule for students who get no credit for items in the first section of the grade-appropriate test. For students in Grades 3 and 4, the examiner is permitted to decide whether to reverse to the Grade 1 or Grade 2 band. We decided to specify the reversal grade based on students' performance on the TOWRE-SW. If students scored lower than 1.5 *SDs* below the standardized mean, they would reverse to the Grade 1 test and if they scored higher than 1.5 *SD*s below the standardized mean, they would reverse to the Grade 2 test. A total of 61 students with RD reversed to an earlier grade; none of the students with typical achievement required the reversal rule. The Psychological Corporation (2005) test manual provides norm-referenced score tables for students who reverse to a lower grade, so students who reverse can still be compared with those who do not. We also established a 5 minute limit on the amount of time students were given to read the passages (none of which was longer than 150 words), although none was specified in the test manual. Students were still asked all comprehension questions, even if they appeared to be reading when asked to stop after 5 minutes. The split-half reliability of the WIAT2-RC ranges from .94 to .96 for children ages 7 to 12. The interscorer reliability for the free-response items on the Reading Comprehension subtest is .94.

The next test was the Woodcock-Johnson-Revised Cross Out subtest (WJR-CO; Woodcock & Johnson, 1989, 1990), a test of processing speed that requires students to identify object matches in a row of items. The split-half reliability of the WJR-CO is .64 for 6 year-old students and .67 for 9 year-old students. Students were also administered the Woodcock Reading Mastery Test-Revised (Woodcock, 1998), Word Attack (WRMTR-WA) and Word Identification (WRMTR-WI) subtests, which measure pseudoword and sight word reading, respectively. Unlike the TOWRE, these tests are not timed, although students are allowed only 5 seconds to respond to each item. The split-half reliabilities are .91 and .97 for the WRMTR-WA and WI respectively for Grade 3 students; reliabilities were not reported for Grades 2 or 4. The final test for Session 1 was the Comprehensive Test of Phonological Processing, Elision (CTOPP-E; Wagner, Torgesen, & Rashotte, 1999) subtest, in which students are required to repeat a stimulus word minus a syllable or phoneme (e.g., "say *pancake* without saying *cake*" or "say *cup* without saying /k/"). The test-retest reliability of the CTOPP-E is .88 for students between ages 5 and 7 and .79 for students between ages 8 and 17.

Session 2 measures

The first test comprised two subtests of the Oral and Written Language Scales (Carrow-Woolfolk, 1995), namely Listening Comprehension (OWLS-LC) and Oral Expression (OWLS-OE). The OWLS-LC required students to select one picture from a set of four that matches a statement by the examiner while the OWLS-OE requires students to produce or complete a sentence in response to an orally presented stimulus. The reliability for OWLS-LC ranges from .75 to .87 for children ages 7 to 12, the range in our sample. The reliability for the OWLS-OE ranges from .83 to .90 for the same range. The reliability of the Oral Composite ranges from .89 to .91. Students were also administered a pair of Grade 2 oral reading fluency passages from a set of Curriculum-Based Measurement (CBM) passages designed to monitor progress (Fuchs, Fuchs, Hamlett, Walz, & Germann, 1993). The passages were selected because they were representative of the entire collection of Grade 2 passages and contained no extremely low frequency words. Students were given one minute to read each passage, and the number of correct words read was recorded.

Students were also administered the CTOPP Rapid Letter Naming (CTOPP-RLN; Wagner et al., 1999) subtest, in which students were asked to read four rows of letters as quickly as possible. The students' scores were the times to read all letters. The test-retest reliability for the RLN subtest is .97 for children ages 5 to 7, .72 for children ages 8 to 17, and .92 overall.

Session 3 measures

For the final session, we administered the CTOPP Rapid Digit Naming (CTOPP-RDN; Wagner et al., 1999) subtest, which is identical to the CTOPP-RLN except students name digits instead of letters. The test-retest reliability of the CTOPP-RDN is .91 for children ages 5 to 7, .80 for children ages 8 to 17, and .87 overall.

We then administered three subtests from the Working Memory Test Battery for Children (WMTB; Pickering & Gathercole, 2001). The Listening Recall (WMTB-LR) subtest asks students to repeat sequences of one-syllable words of increasing length, beginning with one word and continuing increasing to as many as nine. The Block Recall (WMTB-BR) subtest, a Corsi span task, asks students to replicate the examiner's pointing sequence on a board of randomly distributed blocks. The pointing sequences increase in length, beginning with 1 and possibly reaching 9. The final subtest, the Backward Digit Recall (WMTB-BD) task asks students to repeat aurally presented sequences of digits in reverse order. For example, if the examiner says "2, 5," the examinee says "5, 2." The sequences begin with two digits and increase to as many as seven. The test-retest reliabilities for the WMTB LR, BR, and BD subtests are .80, .63, and .53 for children ages 5 to 8 and .64, .43, and .71 for older children.

The final task was the Wechsler Intelligence Test for Children, 3rd Edition, Object Assembly (WISC3-OA; Wechsler, 1991) subtest. The object assembly task requires students to complete puzzles of increasing difficulty and complexity while timed. Students' scores reflect the number of correct junctions they link within the specified time. The split-half reliability of the WISC3-OA subtest ranges from .65 to .75 for ages 7 to 12, the range in our sample.

Teacher measures

In addition to testing, teachers filled out two kinds of forms. First, they were asked to complete demographic forms providing information about the student's age, gender, ethnicity, and disability status. In addition, they completed the Conners' Teacher Rating Scale, Short Form (Conners, 1997). The internal consistency reliability for the Conners' ranges from .8 to .93 for students in age range sampled (7 to 12).

Procedures

Test training

Measures were administered by 16 research staff, including the author, his co-project coordinator, one second-year doctoral student, and 13 Masters' students. Staff members received training on administration of all measures. Training included demonstrations and practice. Afterwards, staff practiced administering the measures to each other. Before they were permitted to administer measures to students, they were required to meet 90% procedural fidelity and 90% interscorer reliability criteria separately for each measure. If staff did not meet the criterion, they practiced the tests further before attempting administration or scoring again. No staff member conducted testing before meeting criteria.

Test administration

Tests were administered on four occasions. Testing was conducted at schools during times approved by the students' teachers. Testing times did not interfere with instruction or compete with recess, lunch, special classes such as physical education, or school assemblies. Students were tested in the quietest available locations at the school, often a library or empty classroom. The first occasion of testing was the screening. The other test sessions, referred to as Sessions 1, 2, and 3, were conducted only for those students who met screening criteria. The tests are listed in Table 4.

Table 4. Tests administered at each test session

Screening	Session 1	Session 2	Session 3
Wechsler Abbreviated Scale of Intelligence, Vocabulary subtest (WASI-V)	Wechsler Individual Achievement Test, II, Reading Comprehension subtest (WIAT2-RC)	Oral and Written Language Scales, Listening Comprehension subtest (OWLS-LC)	Comprehensive Test of Phonological Processing, Rapid Digit Naming subtest (CTOPP-RDN)
Wechsler Abbreviated Scale of Intelligence, Matrix Reasoning subtest (WASI-MR)	Woodcock-Johnson, Revised, Test of Cognitive Abilities, Cross-Out subtest (WJRCO)	Oral and Written Language Scales, Oral Expression subtest (OWLS-OE)	Working Memory Test Battery for Children, Word List Recall subtest (WMTB-WLR)
Woodcock-Johnson III Test of Achievement, Passage Comprehension subtest (WJ3-PC)	Woodcock Reading Mastery Test, Revised, Word Identification subtest (WRMTR-WI)	Curriculum-Based Measurement, Grade 2 Passage Fluency (2 passages)	Working Memory Test Battery for Children, Block Recall subtest (WMTB-BR)
Test of Word Reading Efficiency, Phonemic Decoding subtest (TOWRE-PD)	Woodcock Reading Mastery Test, Revised, Word Attack subtest (WRMTR-WA)	Comprehensive Test of Phonological Processing , Rapid Letter Naming subtest (CTOPP-RLN)	Working Memory Test Battery for Children, Backward Digit Recall subtest (WMTB-BD)
Test of Word Reading Efficiency, Sight Word subtest (TOWRE-SW)	Comprehensive Test of Phonological Processing, Elision subtest (CTOPP-E)		Wechsler Intelligence Scale for Children, III, Object Assembly subtest (WISC3-OA)
Wide Range Achievement Test, Arithmetic subtest (WRAT3-A)			
Key Math, Revised, Problem Solving subtest (KMR-PS)			

To put students at ease, staff members began each testing session by engaging them in games. For screening, staff members presented students with two drawings and asked them to choose one and tell a story about it. For Sessions 1, 2, and 3, staff members played two short games of Connect 4, a game similar to tic-tac-toe, at the beginning and end of each testing session. Staff members reported that students enjoyed the games.

Scoring and data entry accuracy

To assure scoring accuracy, all scores recorded by staff during test administration were checked by a second rater. Any scoring errors were corrected. If a staff member did not administer enough items for tests with basals and ceilings, the staff member returned to the school to complete the administration. For data entry, scores for all tests were entered twice in separate databases. The scores in each database were compared to be sure they were correct. In the event of discrepancies, the original test protocols were consulted and discrepancies were corrected.

Analysis

To examine group differences on the cognitive and reading measures, profile analyses were conducted using MANOVA. Profile analysis compares performance across groups on multiple measures with three types of tests (Tabachnick & Fidell, 2007). The first test, called the *elevation* or levels, test examines whether there are differences between groups (TA and the four RD subtypes) averaged across measures. This test allows us to determine whether the overall performance of the groups differs, answering our first, third, and sixth research questions (i.e., Do students with TA perform better than those with RD? Do those with RD-only, RD+MD, RD+ADHD, and RD+MD+ADHD have different cognitive levels overall? Do those with RD-only, RD+MD, RD+ADHD, and RD+MD+ADHD have different reading levels overall?).

The second profile analysis test, called the *shape* or parallelism test, examines whether the different RD subtypes have different scores on the different tests. This test is very important in the current study because shape effects suggest that students of different RD types perform differently on different tests, answering the other research questions: Do students with TA have a different pattern of cognitive strengths and weaknesses than those with RD? (RQ#2) Among the RD subtypes, do students have different patterns of strength and weakness? (RQ#4) Do students with TA have different patterns of reading achievement? (RQ#5) Among the RD subtypes are there different patterns of reading achievement? (RQ#7).

The third test, called the *flatness* test, examines whether the scores on the different measures—not considering group—are significantly different. The flatness test is not of theoretical interest here. Therefore, we do not employ it.

Profile analysis requires that all scores are on the same scales, so we *z*-scaled all test scores ($M = 0$, $SD = 1$). The sample, however, included more than 4 times as many students with RD as with TA, so a weighting procedure was used to calculate a mean and standard deviation for the raw scores in the sample as though the data were from a normal distribution. We tested 84 teacher-identified TA students with scores above the 25th percentile but only included those 51 with scores above the 35th percentile. For the weighting, however, all 84 TA students were included. A simulation was run to determine appropriate weights for students with and without RD, and each student with RD was given a weight of 0.357 and each student with TA a weight of 2.837. The resulting *z* scores were used in all subsequent analyses. The z-scores for each group, along with univariate ANOVA *F* statistics for each measure with group as the between-subjects variable, are given in Table 6.

Table 6. Means and standard deviations and univariate *F* statistics for all measures in *SD* units

		TA *n* = 51		RD-only *n* = 47		RD+MD *n* = 105		RD+ADHD *n* = 13		RD+MD+ADHD *n* = 47	
	Univariate *F*	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
						Reading measures					
WIAT2-RC	76.37	0.75	(0.50)	-1.00	(0.73)	-1.25	(0.80)	-1.17	(0.65)	-1.28	(0.74)
WRMT-WI	51.41	0.58	(0.66)	-1.08	(0.89)	-1.30	(0.82)	-1.11	(0.66)	-1.40	(1.00)
WRMT-WA	81.70	0.57	(0.70)	-1.05	(0.64)	-1.28	(0.64)	-1.37	(0.45)	-1.37	(0.68)
CBM	64.02	0.52	(0.79)	-1.03	(0.61)	-1.21	(0.62)	-1.00	(0.64)	-1.22	(0.74)
						Cognitive measures					
OWLS-LC	12.57	0.42	(0.98)	-0.25	(1.05)	-0.66	(0.95)	-0.53	(1.36)	-0.80	(0.94)
OWLS-OE	24.58	0.58	(0.86)	-0.51	(0.94)	-0.94	(1.02)	-0.52	(0.82)	-0.97	(0.91)
WMTB-WLR	11.28	0.41	(0.97)	-0.40	(1.10)	-0.59	(0.90)	-0.58	(0.69)	-0.71	(1.03)
WMTB-BDR	16.09	0.35	(0.82)	-0.14	(0.76)	-0.74	(0.91)	-0.63	(1.00)	-0.66	(0.84)
WMTB-BR	4.75	0.24	(0.91)	0.10	(0.80)	-0.31	(0.92)	-0.11	(0.94)	-0.36	(0.97)
CTOPP-RAN	8.96	0.28	(0.61)	-0.59	(1.18)	-0.97	(1.44)	-0.69	(1.62)	-0.77	(1.23)
CTOPP-E	46.27	0.56	(0.91)	-0.79	(0.61)	-0.86	(0.60)	-0.82	(0.34)	-0.90	(0.61)
WJR-CO	7.51	0.26	(0.94)	-0.29	(1.16)	-0.58	(0.98)	-0.69	(1.43)	-0.70	(0.96)
WISC3-OA	4.72	0.3	(1.02)	-0.15	(1.06)	-0.40	(0.97)	-0.42	(1.04)	-0.41	(1.12)

Note: All univariate *F* statistics (df = [4, 258]) significant at the .0001 level, except WISC3-OA, *p* = .001.

Although this norming sample—particularly for students with TA—was small and only the 32 students between the 25th and 35th percentile were not in both the norming sample and the subsequent analysis, we believe these locally-normed scores are better for profile analysis. The norms provided by test developers may be valid for the individual test, but each test has a different norming sample with potentially different characteristics (e.g., not all tests were normed in the same country).

Finally, for analysis, some measures were combined. For the cognitive profile analysis, the two lexical retrieval speed measures (CTOPP-RLN and CTOPP-RDN) were combined into a single scale. For the reading profile analysis, the two fluency passages were combined into a single score.

Cognitive profile procedure

The cognitive profile analysis was conducted in a series of steps designed to answer the four related research questions. For the TA versus RD comparison, the elevation tests determine whether cognitive differences exist (RQ#1), and the shape tests show where these cognitive differences might be located (RQ#2). We conducted two tests for each research question, one for TA students versus all RD subtypes together and a second for TA versus RD-only. Two tests were conducted because the selection of students with RD+MD, RD+ADHD, and RD+MD+ADHD was based on multiple measures, making it more likely they would have lower cognitive performance than students with RD-only. The TA versus RD-only test allowed us to consider whether those with TA were still higher on cognitive measures when we removed the RD groups meeting more stringent criteria.

For the third and fourth research questions (Do students with RD subtypes have different elevation [RQ#3] and shape [RQ#4] to their cognitive profiles?), we compared only RD subtypes in the profile analysis. Here again, two separate tests were used, the first comparing all RD subtypes against each other and the second collapsing the RD-only and RD+ADHD subtypes and the RD+MD and RD+MD+ADHD subtypes. The latter comparison was done because students with RD and ADHD may not have many cognitive differences such that RD+ADHD have similar patterns to RD-only and RD+MD+ADHD similar patterns to RD+MD on cognitive measures. Across all cognitive analyses, we conducted four separate planned contrasts, so it was necessary to control for family-wise error rate. To do this, we set the α level at .05/4, or .0125, following Fletcher et al. (1994).

Reading profile procedure

For the fifth question (Does the shape of reading achievement of RD and TA differ?), we conducted the TA versus RD subtypes and TA versus RD-only analyses, just as we did above, to consider the effect of RD compared to TA in the presence and absence of comorbidity. For the questions regarding RD subtypes (Are there differences in the reading achievement elevation [RQ#6] and shape [RQ#7] among the RD subtypes?), we compared all four RD subtypes and then collapsed the ADHD subtypes into RD-only and RD+MD, as we did for the cognitive profiles. Again, we conducted four separate analyses and set the α level at .0125.

Posthoc analyses

The final step in the analysis was to conduct a pure shape analysis when the MANOVA revealed a significant shape effect. To examine the interaction contrasts, any elevation and flatness effects are removed from the analysis by collecting residuals from an ANOVA with group and measure as factors. These residuals are then subjected to a final MANOVA and the canonical structure coefficients are examined to determine which variables have the greatest differential effect on performance across groups. To evaluate whether these residual comparisons are significant, the residuals are subjected to bootstrap *t*-tests (Efron, 1982) that exact a penalty for conducting nine tests and thereby control the probability of false results (Benjamini & Hochberg, 1995). The correction was accomplished using SAS PROC MULTTEST (Westfall, Tobias, Rom, Wolfinger, & Hochberg, 1999) with 100,000 bootstrap resamples.

CHAPTER IV

RESULTS

Overall Tests of Elevation and Shape

The results of the profile analysis are reported here and are also summarized in Table 7.

Table 7. MANOVA Results (*F* statistics for analyses using Wilks' Lambda criteria)

	Cognitive profiles		Reading profiles	
	Elevation (group)	Shape (measure x group)	Elevation (group)	Shape (measure x group)
TA vs. RD together	116.22 ***	6.89 ***	385.81 ***	3.03
TA vs. RD-only	40.91 ***	6.17 ***	196.95 ***	1.09
All RD compared	3.87 *	0.73	1.96	0.62
RD vs. RD+MD	9.88 *	1.22	5.19	0.22

Note: TA = Typical achievement; RD = Reading disability; RD+MD = Reading disability plus math disability; ADHD = Attention-deficit/hyperactivity disorder; * = $p < .0125$; ** = $p < .001$; *** = $p < .0001$.

For the first test for cognitive variables contrasting TA and the RD subtypes, the elevation effect was significant, $F(1, 256) = 116.22$, $p < .0001$). The shape effect was also significant, $F(8, 249) = 6.89$, $p < .0001$). For the second test contrasting TA and RD-only, both effects remained significant, elevation, $F(1, 96) = 40.91$, $p < .0001$) and shape, $F(8, 89) = 6.17$, $p < .0001$. For the first test of cognitive variables contrasting the RD subtypes, the elevation effect was significant, $F(3, 203) = 3.87$, $p = .010$) but the shape effect was not, $F(24, 569) = 0.73$, $p = .83$. For the second test, contrasting RD and RD+MD by collapsing ADHD into those groups, the elevation effect was significant, $F(1, 205) = 9.88$, $p = .002$ but again the shape effect was not, $F(8, 198) = 1.22$, $p = .29$.

For the first contrast of TA and RD subtypes on reading measures, the shape effect was not significant, $F(3, 259) = 3.03$, $p = 0.03$. For the second contrasting TA and RD-only, the shape was again not significant, $F(3, 94) = 1.09$, $p = .36$. For the first contrast of RD subtypes on reading measures, neither the elevation ($F[3, 208] = 1.96$, $p = .12$) nor the shape effect ($F[9, 502] = 0.62$, $p = .78$) was significant. For the second test comparing RD and RD+MD and collapsing ADHD into those groups, elevation remained non-significant, $F(1, 210) = 5.19$, $p = .02$, as did shape, $F(3, 208) = 0.22$, $p = .88$.

Analysis of Shape Effects

Analysis of shape is only possible when overall shape effects are significant. For this analysis, therefore, shape was examined only for the cognitive profiles for the TA versus the RD subtypes combined and TA versus RD-only contrasts. The adjusted means and standard deviations, as well as the canonical correlations, raw *p* values, and bootstrap *p* values that control family-wise error rate, are reported in Table 8.

Table 8. Cognitive variables' adjusted values used in shape analysis

	TA n = 51	All RD combined n = 212				RD-only n = 47			
	M (*SD*)	*M* (*SD*)	CanCorr	Raw *p*	Boot *p*	*M* (*SD*)	CanCorr	Raw *p*	Boot *p*
OWLS-LC	0.027 (0.983)	0.027 (0.975)	.129	.827	1.000	0.076 (1.048)	.445	.814	1.000
OWLS-OE	0.343 (0.864)	-0.044 (0.929)	-.670	.004	.036	-0.029 (0.942)	-.903	.044	.290
WMTB-WLR	0.011 (0.970)	0.013 (0.969)	.133	.930	1.000	-0.092 (1.100)	-.053	.624	1.000
WMTB-BR	-0.414 (0.907)	0.116 (0.896)	.618	.000	.003	0.159 (0.802)	.567	.001	.011
WMTB-BD	-0.032 (0.823)	0.026 (0.867)	-.034	.766	1.000	0.189 (0.762)	.334	.172	.757
CTOPP-RAN	0.107 (0.613)	0.006 (1.332)	.041	.495	.996	-0.055 (1.183)	.048	.393	.979
CTOPP-E	0.352 (0.910)	-0.086 (0.597)	-.638	.000	.000	-0.281 (0.607)	-.730	.000	.001
WJR-CO	-0.133 (0.937)	0.053 (1.045)	.138	.300	.937	0.034 (1.163)	.034	.432	.988
WISC3-OA	-0.260 (1.019)	0.071 (1.023)	.384	.044	.294	0.000 (1.060)	.328	.220	.844

Note: CanCorr = Standardized canonical correlation for TA vs. All RD and TA vs. RD-only analyses, respectively. Raw *p* = *p* value for contrast uncorrected for multiple comparisons; Boot *p* = *p* value for bootstrap test controlling for multiple tests. OWLS = Oral and Written Language Scales; LC = Listening Comprehension subtest; OE = Oral Expression subtest; WMTB = Working Memory Test Battery for Children; WLR = Word List Recall subtest; BR = Block Recall subtest; BDR = Backward Digit Recall subtest; CTOPP = Comprehensive Test of Phonological Processing; RAN = Rapid automatic naming, a measure of lexical retrieval speed; CTOPP-E = CTOPP Elision subtest; WJR-CO = WJR Cross Out subtest; WISC3-OA = Wechsler Intelligence Scale for Children, Third Edition, Object Assembly subtest.

The means for the TA, all RD, and RD-only groups are also plotted in Figure 3. The shape analysis revealed a relative strength for all RD subtypes and the RD-only subtype on WMTB-BR (canonical correlations of .62, bootstrapped p = .003, and .57, bootstrapped p = .01, respectively). In terms of areas of relative weakness, all RD subtypes showed relatively low performance on OWLS-OE (canonical correlation of -.67, bootstrapped p = .04) and CTOPP-E (canonical correlation = -.64, bootstrapped p < .0001). For RD-only versus TA, relative weakness was found only on CTOPP-E (correlation = -.64, p = .001).

Posthoc Power Analyses

A posthoc statistical power analysis was conducted to be certain that some nonsignificant findings—particularly for shape—could be explained by weak power. Using G*Power 3.1.2, we calculated power for the MANOVA shape effects (see Table 9). We found that small effects (*ES* = 0.20) could be detected for the analyses involving all students, but power only reached .80 for cognitive effect sizes of 0.22 and 0.48 for the RD subtype and TA versus RD-only analyses. For reading, power of .80 was only reached for the TA versus RD-only analyses for an effect size of 0.40.

Table 9. Post-hoc power analyses (minimum detectable *ES* and achieved power) for shape effect in profiles

	Cognitive (measures = 8)				Reading (measures = 4)			
		Effect size				Effect size		
		0.1	0.2	0.5		0.1	0.2	0.5
	Min ES at power = .80	Power	Power	Power	Min ES at power = .80	Power	Power	Power
Groups = 5 & N = 263	0.18	.15	.92	1.00	0.19	.20	.94	1.00
Groups = 4 & n = 212	0.22	.08	.68	1.00	0.18	.18	.89	1.00
Groups = 2 & n = 212	0.31	.05	.28	1.00	0.26	.08	.46	1.00
Groups = 2 & n = 98	0.48	.02	.09	.85	0.4	.04	.17	.96

Note: Group sizes and *n* s in left column are for--in descending order--analysis with all students, reading disability subtypes only, reading disaiblity subtypes with ADHD collapsed, and reading disability-only subtype versus typically-achieving. The alpha was set to .0125 to correct for multiple tests.

One elevation analysis was also conducted, for the RD subtype comparisons for the reading profile, because the elevation effect was nonsignificant for this analysis. Setting α at .0125 and using the average correlation among reading measures of .70, we could calculate an effect size of 0.24 with power of .80, 0.26 with power of .90, and 0.42 with power approaching 1. When collapsing the ADHD subgroups into RD-only and RD+MD, we could calculate an effect size of .20 with power of .80, 0.23 with power of .90, and 0.37 with power approaching 1.

CHAPTER V

DISCUSSION

Summary of Findings

We designed this study to answer seven major research questions, four concerned with questions about the cognitive profiles of students with RD and TA peers and three with the reading profiles of these students. For the cognitive profiles, our first question was whether students with RD collectively had lower cognitive performance than their TA peers. We found that they did. Even students with RD-only had lower overall cognitive performance than their TA peers. For RQ#2, we asked whether students with RD had a different pattern of cognitive strengths and weaknesses than their TA peers. We found that they did. Students with RD appeared to have relative strength on the WMTB Block Recall subtest, a measure of visuospatial working memory. Students with RD appeared to be relatively weak phonological awareness on the CTOPP-E. Students with RD also appeared relatively weak on oral language expression on the OWLS-OE, although this was not significant for the RD-only versus TA contrast. Figure 1 displays the elevation differences, and Figure 2 indicates areas of particular strength and weakness for students with RD, relative to their TA peers.

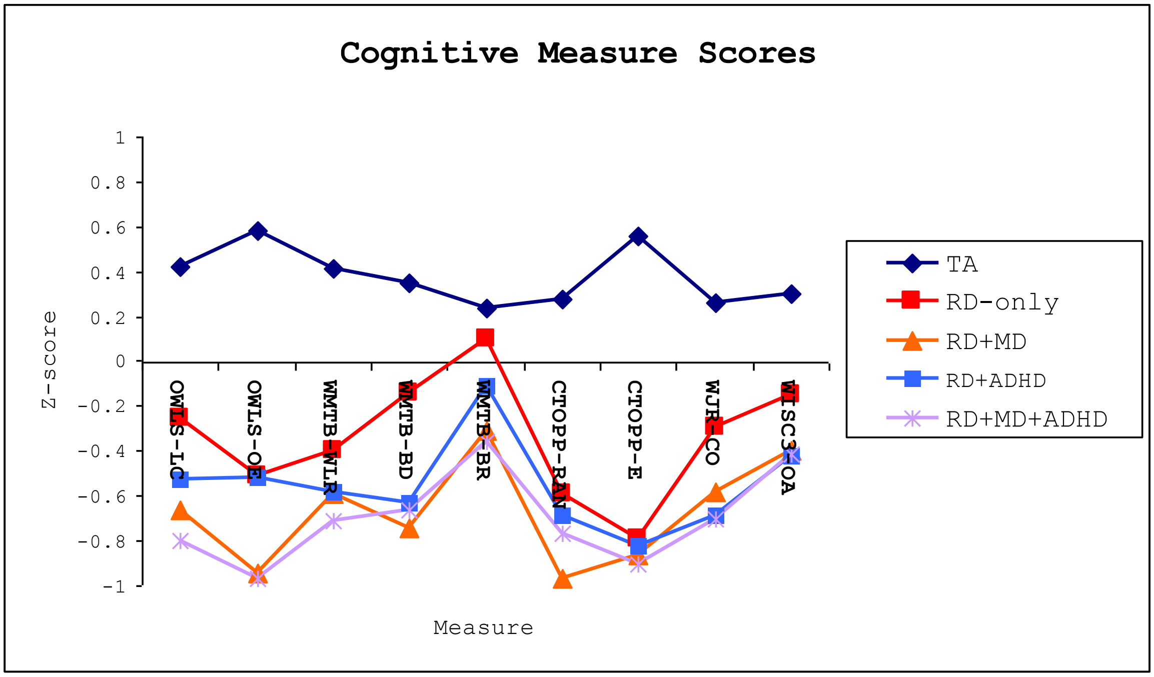

Figure 1. Locally-normed, z-score transformed performance on cognitive measures, by group. TA = Typically-achieving; RD = Reading disability; MD = Math disability; ADHD = Attention-deficit/hyperactivity disorder. OWLS-LC = Oral and Written Language Scales, Listening Comprehension subtest; OWLS-OE = Oral and Written Language Scales, Oral Expression subtest; WMTB-WLR = Working Memory Test Battery for Children, Word List Recall subtest; WMTB-BR = Working Memory Test Battery for Children, Block Recall subtest; WMTB-BDR = Working Memory Test Battery for Children, Backward Digit Recall; CTOPP-RAN = Comprehensive Test of Phonological Processing Rapid Automatic Naming subtests combined; CTOPP-E = Comprehensive Test of Phonological Processing, Elision subtest; WJR-CO = Woodcock-Johnson Test of Cognitive Abilities-Revised, Cross Out subtest; WISC3-OA = Wechsler Intelligence Scale for Children, 3rd Edition, Object Assembly subtest.

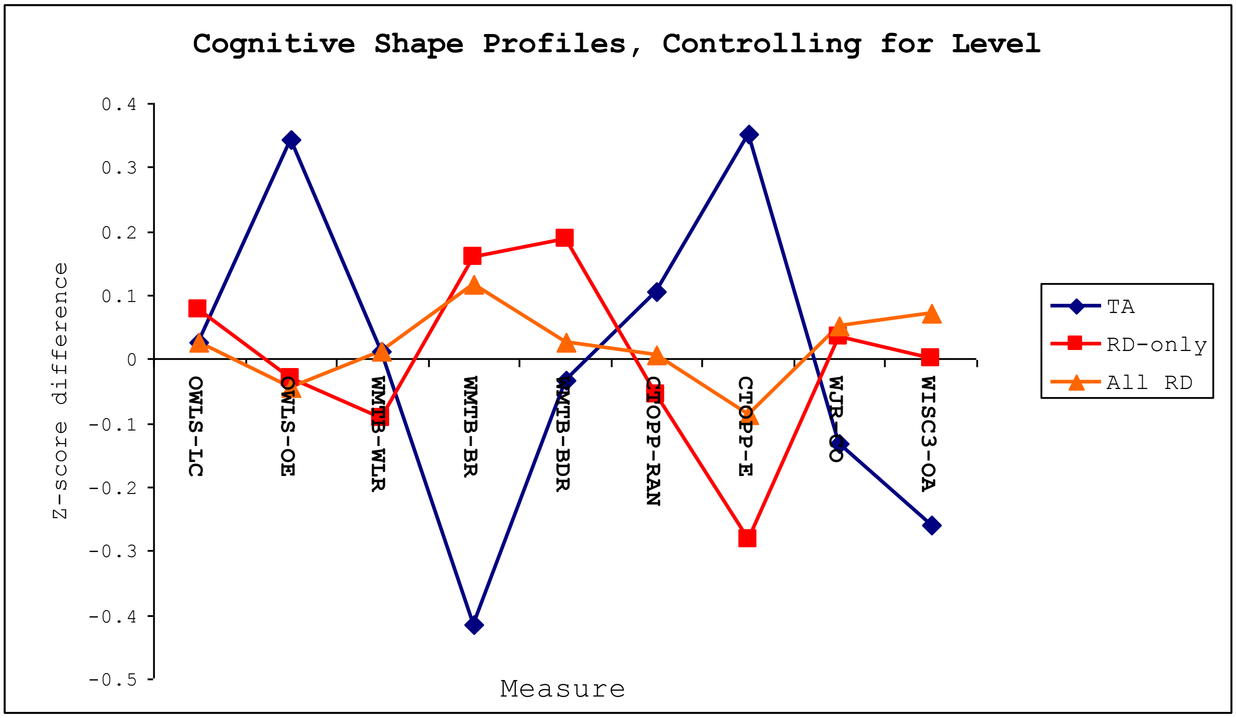

Figure 2. Shape profiles for cognitive variables. The elevation effect has been removed, emphasizing points of relative strength and weakness. Students with TA, for example, are higher than those with RD on WMTB-BR, but their relative strength is much weaker so their level-controlled scores are below average. Note: TA = Typically-achieving; RD = Reading disability. OWLS-LC = Oral and Written Language Scales, Listening Comprehension subtest; OWLS-OE = Oral and Written Language Scales, Oral Expression subtest; WMTB-WLR = Working Memory Test Battery for Children, Word List Recall subtest; WMTB-BR = Working Memory Test Battery for Children, Block Recall subtest; WMTB-BDR = Working Memory Test Battery for Children, Backward Digit Recall; CTOPP-RAN = Comprehensive Test of Phonological Processing Rapid Automatic Naming subtests combined; CTOPP-E = Comprehensive Test of Phonological Processing, Elision subtest; WJR-CO = Woodcock-Johnson Test of Cognitive Abilities-Revised, Cross Out subtest; WISC3-OA = Wechsler Intelligence Scale for Children, 3rd Edition, Object Assembly subtest.

In RQ#3, we contrasted the RD subtypes. We considered whether there might be differences in the overall cognitive levels of those students with RD-only, RD+ADHD, RD+MD, and RD+MD+ADHD. We did find these differences, with students with RD-only having higher performance than the other groups. We found that when we collapsed the ADHD groups into the RD groups, the difference in elevation was still present. For RQ#4, we considered different patterns of strength and weakness among the subtypes by measure, particularly given the idea that some cognitive processes might be more relevant for mathematics than reading. We did not find such differences, even when we collapsed ADHD into the RD groups, suggesting that students with different RD subtypes did not have markedly different patterns of cognition, even if they were at different levels.

Our remaining research questions concerned the reading profiles of these students, shown in Figure 3. For RQ#5, we asked whether students with RD and TA had different areas of strength and weakness in reading. We found that they did not. In RQ#6, we considered differences in the level of reading performance by RD subgroup. We did not find such differences, even when we collapsed ADHD into the RD-only and RD+MD groups. Finally, we examined in RQ#7 whether students with RD had different patterns of reading ability. Again, we found no differences, even when collapsing ADHD.

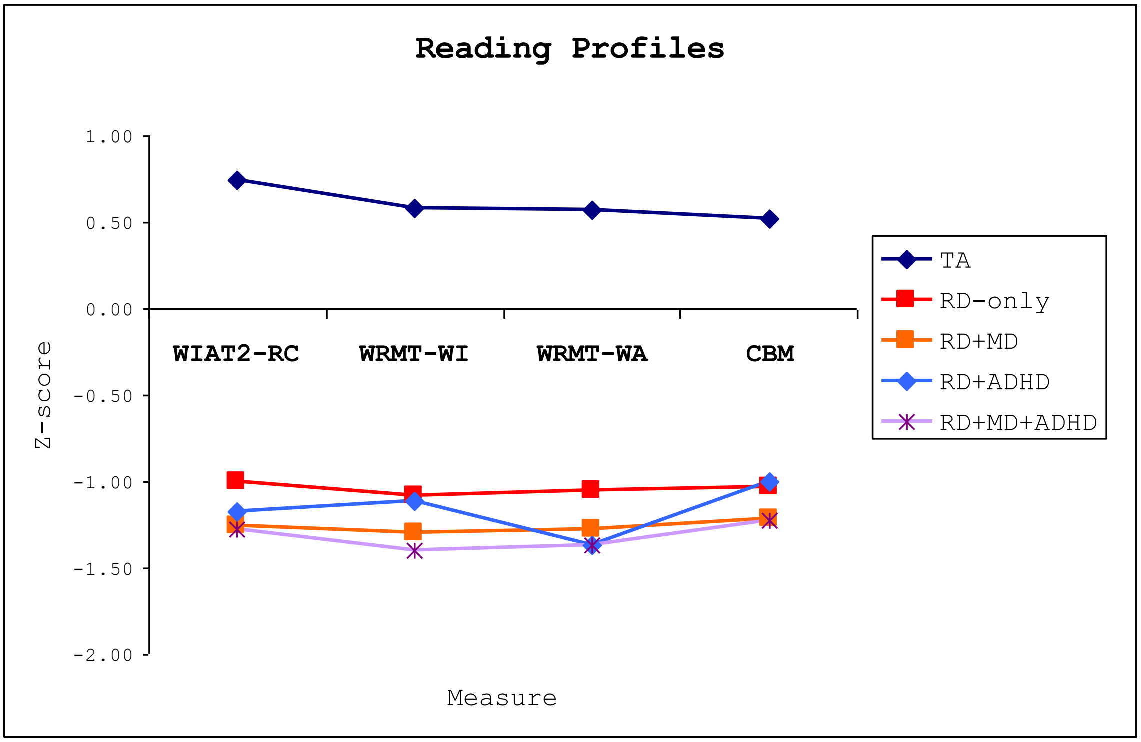

Figure 3. Locally-normed, z-score transformed student performance on reading measures, by group. Note: TA = Typically-achieving; RD = Reading disability; MD = Math disability; ADHD = Attention-deficit/hyperactivity disorder. WIAT2-RC = Wechsler Individual Achievement Test II, Reading Comprehension subtest; WRMT-WI = Woodcock Reading Mastery Test-Revised, Word Identification subtest; WRMT-WA = Woodcock Reading Mastery Test-Revised, Word Attack subtest; CBM = Curriculum-based measurement 2nd grade fluency test (average of two passages).

Key Findings

Four central ideas emerge from this study. The first is that students with RD differ from their peers with TA in their patterns of cognitive performance. Students with RD appear to have relatively strong visuospatial working memory but weak phonological awareness and expressive language skills compared to their peers with TA. Weak phonological awareness is consistent with the literature, which suggests the salience of this dimension for RD (e.g., Ellis, 1985; Stanovich, 1988). The presence of a language deficit also aligns with the literature because language is linked with reading comprehension ability (e.g., Cain & Oakhill, 2006; Nation, Clarke, Marshall, & Durand, 2004), a skill that was impaired in about three quarters of the students in our sample identified with RD.

One important goal of this study was to identify areas of particular strength and weakness in students with RD that may be relevant for intervention, and we identified three such areas. This study is descriptive, so interventions remediating weaknesses in phonological processes and language could not be said to succeed based on this study alone. However, phonological awareness has long been a component of successful interventions for students with reading difficulty. Because our findings align with this approach and also identify weakness in oral language for students with RD, it might worthwhile to consider an oral language component in future interventions for students with reading problems. The presence of particular strength in visuospatial short-term memory also might be exploited in future intervention. The way in which these strengths and weaknesses might be addressed in intervention is, however, beyond the scope of this paper.

Second, the cognitive performance of students with RD is lower than of TA students, and the cognitive performance of those with RD+MD is lower than that of students with RD-only. This finding appears to corroborate the notion that students with RD may be at the lower end of the cognitive distribution (Stanovich & Siegel, 1994; Wagner & Garon, 1999) and students with RD+MD may be lower still. Examination of the IQ subtest scores of students in this study (Table 5) provides additional descriptive support for this possibility—students with more difficulties have lower IQ scores: WASI full-scale IQ $\bar{X}$s (*SDs*): TA = 106.6(11.0); RD-only = 91.6(11.6); RD+MD = 83.6(10.7); RD+ADHD = 85.2(10.1); RD+MD+ADHD = 82.8(11.1). Moreover, examination of the standard scores for the cognitive measures based on publisher-provided norms (see Table 10) suggests these students are performing below normative expectations. This aligns with findings from earlier studies (e.g., Fletcher et al., 1994; Stanovich & Siegel, 1994) and meta-analyses (Hoskyn & Swanson, 2000; Stuebing et al., 2002) that students with RD appear similar to those with low achievement. It runs counter to the idea that students with RD represent an unexpected hump in the reading achievement distribution (e.g., Rutter & Yule, 1975).

Table 10. Means and standard deviations for all measures using norms (where available)

	TA *n* = 51		RD-only *n* = 47		RD+MD *n* = 105		RD+ADHD *n* = 13		RD+MD+ADHD *n* = 47	
	M	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)	*M*	(*SD*)
					Reading measures					
WIAT2-RC	104.47	(7.41)	77.36	(9.52)	73.12	(10.36)	74.00	(6.61)	70.53	(8.53)
WRMT-WI	104.33	(8.84)	84.26	(8.38)	82.43	(8.14)	85.46	(6.72)	80.04	(8.16)
WRMT-WA	109.02	(9.37)	86.91	(10.47)	83.45	(11.10)	83.69	(11.39)	80.19	(11.22)
CBM[a]	125.94	(35.60)	56.04	(27.29)	48.00	(28.04)	57.46	(28.97)	47.36	(33.24)
					Cognitive measures					
OWLS-LC	95.78	(12.12)	83.96	(12.20)	77.82	(12.56)	82.23	(16.23)	75.87	(11.97)
OWLS-OE	98.1	(10.91)	79.26	(10.40)	73.28	(11.70)	81.54	(8.18)	72.64	(11.59)
WMTB-WLR	95.76	(15.13)	81.32	(18.10)	78.65	(14.54)	78.85	(11.77)	76.17	(15.64)
WMTB-BDR	96.76	(16.98)	84.38	(13.62)	74.40	(14.85)	78.15	(14.71)	74.54	(13.17)
WMTB-BR	92.75	(19.26)	87.11	(17.16)	79.57	(17.54)	84.54	(16.25)	78.30	(16.42)
CTOPP-RAN[b]	10.97	(1.85)	8.49	(1.95)	7.85	(2.25)	9.08	(2.47)	8.24	(2.37)
CTOPP-E[b]	10.47	(2.81)	6.11	(1.77)	5.82	(2.20)	6.62	(1.50)	5.79	(1.79)
WJR-CO	98.16	(11.07)	88.62	(15.63)	84.66	(10.69)	83.54	(25.77)	82.40	(10.62)
WISC3-OA[b]	8.53	(2.67)	6.55	(3.32)	5.83	(3.16)	6.31	(2.56)	5.68	(3.34)

Note: Except where below, all scores are standard scores (*M* = 100; *SD* = 15).
a CBM score given in words per minute
b Scaled score (*M* = 10; *SD* = 3)

On the other hand, the cognitive differences between RD and TA we identified may be partly a product of our selection criteria, which did not require a discrepancy between IQ and achievement and allowed students to be included with IQ scores bordering on the cutoff for intellectual disabilities. Moreover, our TA sample may be too high achieving because they were required to meet minimum cutoffs for four different measures. Our "typical" sample may, therefore, may include students who are higher than the average typical student. Certainly, our sample of RD students performs worse on cognitive measures than our sample of students with TA, but the operational definitions of RD and TA used in our study may distinguish our students from those studies where discrepancies were not found. Generalizing to other students with RD may not be appropriate.

The third finding is that students with RD do not appear to have different cognitive strengths and weaknesses from each other. This finding stands in contrast to some work on comorbidity suggesting RD and MD have domain specific cognitive processes (e.g., Andersson, 2010; Andersson & Lyxell, 2007; Landerl et al., 2009; Rubinsten & Henik, 2006; Rousselle & Noel, 2007; Schuhardt et al., 2008; van der Sluis et al., 2005). Our analysis likely had power to detect effects if they existed (see Table 9), so a lack of power does not mitigate this finding.

This finding is potentially important because it does not provide support for the idea, suggested at the outset, that we can identify areas of particular cognitive weakness to target in different students. If students have RD, the instructional approach we use—even if we focus on the particularly weak areas of phonological awareness and language—could be essentially the same whether or not they also have MD. This is potentially good news because teachers need not become experts in instruction for subtypes of students with RD; knowing how to teach reading to children with RD should be sufficient.

The fourth finding is that students with RD do not have different areas of reading strength and weakness, compared to students with TA or each other. Students with RD have generally uniform weaknesses. This finding is somewhat surprising given the strong phonological loading of the pseudoword reading task, the WRMT-WA. This finding cannot be explained by a lack of power, as we could detect an effect size of 0.18 with power of .80 and 0.34 with power approaching 1. The other related finding, that students with MD do not appear to do significantly worse than those with RD on reading measures, is surprising given that multiple selection criteria often produces identification of a more severe group (see Vukovic & Siegel, 2006 and Compton et al., 2001 for discussion of this topic for reading and lexical retrieval speed). This finding, however, can be potentially explained by insufficient power and should not be considered seriously.

Limitations

The first limitation of this paper concerns the measures. We only used one measure for each domain of interest, except in the case of the lexical retrieval speed (the CTOPP-RLN and CTOPP-RDN). It would have been useful to use multiple measures of each construct. This reduces error variance and produces a more clear representation of each construct. The measures used also had different reliabilities. For some measures, the reliabilities were somewhat low. Low reliability tends to attenuate correlations because more the variance is due to error. We may, therefore, have underestimated some effects.

A second limitation is the possibility of regression effects because we selected students as RD-only based on one criterion but the other groups based on multiple correlated criteria. In the case of RD+MD, for example, reading and math performance are correlated so students identified as MD are also more likely to be RD. By contrast, students with RD-only were selected based only on a reading criterion and a low score due to error might explain their identification. The students with RD-only would be more likely than those with RD+MD to regress toward a higher mean if tested again. On the other hand, we selected students for the RD sample who were already in special education and were identified with reading problems. This improves the reliability of the RD designation, even for RD-only students. This does not however, mitigate the regression problem, especially when we consider that the absence of an elevation effect for RD may have been the result of insufficient power.

A third limitation is with the procedure used to standardize scores for the profile analysis. The procedure we used has been used in other studies (e.g., Compton et al., in press; Fletcher et al., 1994), but the standardization sample is typically much larger. Other studies also include students across the achievement continuum, whereas our selection procedures eliminated students with reading scores between the 16th and 25th percentiles. We accounted for the absence of this group when we weighted the sample, but the hole remains nonetheless. While these limitations reduce our ability to generalize from our findings, we believe that this study contributes to the literature by suggesting the particularly strong effects of phonological awareness, language, and visual short-term memory for RD, finding students with RD to be lower than their TA peers across cognitive measures, showing that students with RD do not differ by subtype in their cognitive profiles for the measures used, and indicating that RD and TA students perform similarly across reading measures.

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