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The Cognitive and Academic Profiles of Reading and Mathematics Learning Disabilities

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Abstract

The purpose of this study was to examine the cognitive and academic profiles associated with learning disability (LD) in reading comprehension, word reading, applied problems, and calculations. The goal was to assess the specificity hypothesis, in which unexpected underachievement associated with LD is represented in terms of distinctive patterns of cognitive and academic strengths and weaknesses. At the start of 3rd grade, the authors assessed 684 students on five cognitive dimensions (nonverbal problem solving, processing speed, concept formation, language, and working memory), and across Grades 3 through 5, the authors assessed performance in each academic area three to four times. Based on final intercept, the authors classified students as LD or not LD in each of the four academic areas. For each of these four LD variables, they conducted multivariate cognitive profile analysis and academic profile analysis. Results, which generally supported the specificity hypothesis, are discussed in terms of the potential connections between reading and mathematics LD.

Keywords

reading disability, math disability, cognitive profiles, academic profiles, specificity hypothesis

The definition of learning disability (LD) has historically centered on the notion of unexpected underachievement. The field has, however, conceptualized and operationalized *unexpected underachievement* in different ways. Relying in part on Samuel Kirk's 1963 definition, the U.S. Office of Education (1968) first formally defined LD in exclusionary terms, as an unexpected disorder not attributable to mental deficiency, sensory disorders, emotional disturbance, or cultural or economic disturbance. In 1977, the Office of Education added guidelines to clarify that a discrepancy between IQ and achievement was a marker for such unexpected underachievement. Because this approach to LD identification resulted in students "waiting to fail" before intervention occurred (with most children identified at fourth or fifth grade) and because of technical difficulties associated with the IQ–achievement discrepancy (for a summary, see Fletcher, Lyon, Fuchs, & Barnes, 2007), the 2004 federal reauthorization of the Individuals with Disabilities Education Act introduced the notion of responsiveness to intervention as an alternative approach for identifying LD. With this approach, unexpected underachievement is referenced against the provision of validated instructional methods; that is, underachievement is unexpected because research documents that the vast majority of students respond to the validated instruction. Such a conceptualization of unexpected underachievement has the advantage of offering prevention services early in a student's schooling, with the hope of avoiding inaccurate LD identification, which is instead the result of poor instruction.

There is, however, a third way of conceptualizing the unexpected underachievement associated with LD: as a profile of strengths and weaknesses across cognitive dimensions or across academic domains. The observation that students with LD experience unexpected pockets of strengths and weaknesses, sometimes referred to as the *specificity* hypothesis, emerged early in the field of LD (e.g., Broca, 1865, as cited in Fletcher et al., 2007; Wiederholt, 1974) and persists today (see Fletcher et al., 2007). The notion is that LD involves specific rather than generalized learning difficulty; the inference is that neurological function selectively impairs some but not other areas of cognitive functioning. Some have extended this notion to denote patterns of strengths and weaknesses unique to an individual, arguing that intervention should be designed to address an individual's unique pattern. Empirical support for this notion is, however, equivocal at best (see).

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In a more productive manner, others argue that the validity of the LD construct finds support in evidence that LD subgroups (e.g., reading vs. mathematics LD) have distinctive patterns of strengths and weaknesses, whereas students without LD manifest an even profile of cognitive dimensions (e.g., Fuchs et al., 2008; Morris et al., 1998).

Unfortunately, research on the cognitive profiles of students with LD is limited. Most studies have instead focused on the cognitive underpinnings of academic difficulty or development. Even there, the bulk of research is confined to early development, with the focus on word-level skills such as decoding and word recognition in reading and on math concepts and arithmetic in mathematics. To increase understanding of the LD construct, additional work is required at the intermediate grades, with a focus not only on lower-level skills but also on more complex aspects of the curriculum. Moreover, to address questions about whether LD simply represents overall low achievement, work is needed specifically to assess whether students with LD have uniformly flat cognitive and academic profiles or whether they demonstrate cognitive and academic profiles of strengths and weaknesses that are distinctive depending on the academic area in which the LD occurs. This was the purpose of the present study. Our focus was word-level skill and reading comprehension as well as calculation and applied problem solving LD at the end of fifth grade. In this introduction, we first summarize findings on the cognitive underpinnings of academic performance in these areas. Then, we describe two key prior studies on the cognitive profiles of LD, one focusing primarily on reading and the other focusing entirely on math. Finally, we explain how the present study extends this body of work.

Cognitive Dimensions Associated With Reading and Mathematics Development

The cognitive dimensions associated with the development of early decoding and word recognition skills are well established. In addition to the importance of phonemic awareness (see Brady & Shankweiler, 1991; Share, 1995), deficits in phonological processing have been causally linked to poor word identification skills through a mechanism that disrupts the development of decoding skills (Brady & Shankweiler, 1991; Bruck, 1992; Bus & Ijzendoorn, 1999; Ijzendoorn & Bus, 1994; Juel, Griffith, & Gough, 1986; Metsala, Stanovich, & Brown, 1998; Rack, Snowling, & Olson, 1992; Shankweiler et al., 1999; Siegel, 1989; Snowling, 2001; Stanovich & Siegel, 1994; Torgesen, 2000; Vellutino et al., 1996). In addition, rapid naming has been shown to have good power in predicting beginning reading word-level skill, above that provided by phonemic awareness skill (Ackerman & Dykman, 1993; Blachman, 1984; Bowers, 1995; Bowers & Swanson, 1991; Compton, 2000; Manis, Doi, & Bhadha, 2000; Manis, Seidenberg, & Doi, 1999; McBride-Chang & Manis, 1996; Meyer, Wood, Hart, & Felton, 1998; Scarborough, 1998; Schatschneider, Francis, Fletcher, & Foorman, 2002; Vellutino et al., 1996; Wagner, Torgesen, & Rashotte, 1994; Wolf, Bally, & Morris, 1986).

Although less mature than the literature on early reading development, a body of work addresses the cognitive underpinnings of early mathematics learning in school, involving number concepts and simple arithmetic. Specialized capacities that affect numerical representations (Butterworth, 1999; Feigenson, Dehaene, & Spelke, 2004), sometimes referred to as number sense, are established predictors (e.g., Fuchs et al., 2010; Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Halberda, Mazzocco, & Feigenson, 2008). More general cognitive abilities are also associated with mathematics learning in the early grades. These include working memory (e.g., Barrouillet, Fayol, & Lathuliére, 1997; Engle, Tuholski, Laughlin, & Conway, 1999; Geary et al., 2007; Swanson & Beebe-Frankenberger, 2004), processing speed (e.g., Bull & Johnston, l997; Fuchs et al., 2005; Hecht, Torgesen, Wagner, & Rashotte, 2001), and phonological processing (e.g., Fuchs et al., 2005; Logie & Baddeley, 1987).

Once early skill with word-level reading and number concepts or arithmetic has been established by the beginning of third grade, however, the cognitive dimensions that predict future development are less clear. In reading, these later reading skills focus largely on multisyllabic decoding and word recognition as well as reading comprehension, which may be associated with working memory (i.e., the capacity to maintain target memory items while processing an additional task; Daneman & Carpenter, 1980). Decoding of multisyllabic words, which may be related to skill at recognizing multisyllabic words, appears to require students to hold associations between letters and sounds while building subsequent associations and tying the series together into a word. In a sample of 8- to 12-year-olds, Conners, Atwell, Rosenquist, and Sligh (2001) showed that, compared to IQ, phonemic awareness, and a general language composite, working memory most reliably distinguished poor and good decoders. Later reading comprehension depends on oral language abilities, including vocabulary knowledge (Dickinson, McCabe, Anastasopoulos, Peisner-Feinberg, & Poe, 2003; McCardle, Scarborough, & Catts, 2001; Muter, Hulme, Snowling, & Stevenson, 2004; Oakhill, Cain, & Bryant, 2003; Scarborough, 2005; Sénéchal, Ouellette, & Rodney, 2006) as well as semantic knowledge (Catts, Fey, Zhang, & Tomblin, 2001; Leach, Scarborough, & Rescorla, 2003; Nation, Marshall, & Snowling, 2001; Nation & Snowling, 1998, 1999).

Working memory and language may also be involved in the development of later mathematics skill. Working memory has been associated with calculation (e.g., Hitch & McAuley, 1991; Siegel & Linder, l984; Wilson & Swanson, 2001) as well as word-problem skill (e.g., LeBlanc & Weber-Russell, 1996; Passolunghi & Siegel, 2004; Swanson & Sachse-Lee, 2001). In terms of calculation problems that involve a series of steps, working memory may contribute to development because these problems require students to select, implement, and monitor strategies for problem solution. With respect to word problems, theoretical frameworks (e.g., Kintsch & Greeno, l985; Mayer, l992) posit the construction of a problem model, in which sets are serially formed on-line as students process the story. For these reasons, the importance of working memory may gain salience as calculation and word problems become more complex in the intermediate grades, although in one of the few studies of the development of fraction skill, conducted from fourth to fifth grade, Hecht (in press) did not find evidence of working memory's contribution. It is also possible that oral language ability may contribute to development, at least in terms of word problems (Fuchs et al., 2006; Jordan, Levine, & Huttenlocher, 1995), for which language demands become increasingly complex in the higher grades.

Even so, given the limited focus in the literature on development in the intermediate grades, it is also possible that additional cognitive dimensions are implicated in these more sophisticated reading and mathematics skills. In the present study, we included three dimensions beyond language and working memory: nonverbal problem solving, concept formation, and processing speed. Nonverbal problem solving may be involved because intermediate tasks require students to decipher relations among characters or numbers in often complex reading or word-problem narratives. For similar reasons, concept formation, which is the ability to identify, categorize, and determine rules, seems plausible. The contributions of nonverbal problem solving and concept formation have been established in the early grades for mathematics word problems (e.g., Fuchs et al., 2005, 2006, 2010) but have not been assessed in the intermediate grades in reading or mathematics. The final cognitive dimension we included was processing speed (i.e., the efficiency with which simple cognitive tasks are executed), as has been shown in early mathematics learning (e.g., Bull & Johnston, l997; Fuchs et al., 2005; Geary et al., 2007; Hecht et al., 2001). We hypothesized that processing speed may also play a role in the development of more complex academic skills because it may affect how quickly lower level skills, which have already been acquired with relative accuracy, can be executed. Slow processing speed creates the possibility that decay in the completion of lower level skills (e.g., connecting sounds and letters in multisyllabic decoding, connecting problems stems with answers in arithmetic) sets in before the more complex skill, which incorporates these tasks, is completed.

Cognitive Subtypes or Profiles of LD

Morris et al. (1998) considered the tenability of subtypes in reading LD, based on their cognitive and language functions, in a sample of 374 children (7.5–9.5 years of age) who were identified as LD on measures of decoding, word recognition, and/or calculations or were identified as having attention-deficit/hyperactivity disorder, typical development, or generalized low performance. Conducting multiple methods of cluster analysis, they identified nine reliable subtypes that represented 90% of the sample, two nondisabled subtypes and seven LD subtypes. Two of the seven LD subtypes were globally deficient in language; four of the five specific LD subtypes manifested weakness in phonological awareness, with variations in rapid naming and lexical skills. The remaining subtype experienced difficulty with verbal and nonverbal measures associated with rate of processing. Results generally support a phonological limitation hypothesis (Liberman, Shankweiler, & Liberman, 1989; Shankweiler & Crain, 1986), at least when reading LD is operationalized in terms of early word-reading skills.

Rather than looking to identify different cognitive profiles of LD within a given academic area, Fuchs et al. (2008) questioned whether the cognitive profile of LD in computation differed from the cognitive profile of LD in problem solving. As with Morris et al. (1998), the focus was on the primary grades, this time third grade; in contrast to Morris et al., multivariate profile analysis, rather than cluster analysis, was used. A representative sample of 924 third graders was assessed on computation and problem solving; was classified as LD with computation, word problems, both domains, or neither domain; and was measured on nine cognitive dimensions. Specific computational LD was associated with strength in language and weaknesses in attentive behavior and processing speed; by contrast, word-problem difficulty was associated with oral language deficiencies.

Contribution of the Present Study

Together, Morris et al. (1998) and Fuchs et al. (2008) provide support for the specificity hypothesis, suggesting that the unexpected underachievement associated with LD may be conceptualized in terms of profiles of cognitive strengths and weaknesses. This work is limited, however, by its focus on the primary grades and the concurrent nature of data collection. In the present study, we extended this literature in three ways. First, we focused on the intermediate grades while expanding the focus to four academic areas that include higher and lower order skills: reading comprehension, word reading, applied problems, and calculations. Second, instead of examining concurrent cognitive profiles, we took a developmental approach, measuring potentially salient cognitive dimensions at the beginning of third grade, then modeling academic development across third, fourth, and fifth grades to identify students with and without LD in each of the four academic domains at the end of fifth grade. Third, in addition to testing the specificity hypothesis in terms of cognitive dimensions, we also conducted profile analysis to examine whether students with LD manifest profiles of academic strengths and weaknesses. The issue of academic profiles is central to the construct of LD. Although we expect students with LD to experience academic difficulty in the area where LD occurs, according to the specificity hypothesis, they should also manifest pockets of relative academic strength. This stands in contrast to generalized academic deficiencies, of comparable magnitude across academic areas, as would be expected for students with mental retardation.

Method

Overview

We followed students over three school years, from the beginning of third grade to the end of fifth grade. In September and October of third grade, we collected information on sociodemographics and assessed students on measures tapping five cognitive dimensions: nonverbal problem solving, processing speed, concept formation, language (three measures), and working memory (two measures). We then modeled the academic learning of these students across three school years to derive a final intercept. The measurement occasions for word reading, applied problems, and calculations were the beginning and spring of third grade and spring of fourth and fifth grades; for reading comprehension, they were spring of third, fourth, and fifth grades. We included 684 students who had complete sociodemographic and cognitive dimensions data along with at least three measurements in each academic area. Using final intercept, we identified students as LD or not learning disabled (NLD; <16th percentile as LD; >39th percentile as NLD) within each academic area. Then, for each of the four LD variables (reading comprehension LD, word reading LD, applied problems LD, calculations LD), we examined sociodemographics and conducted formal cognitive profile analysis (to see which if any LD categories had a distinctive profile of strengths and weaknesses on the five beginning cognitive dimensions) and academic profile analysis (to see which if any LD categories had a distinctive profile of strengths and weaknesses across the four academic areas).

Participants

In a southeastern metropolitan school district, 120 third grade classrooms enrolled in the study in four cohorts, with 30 classrooms entering each year such that data collection spanned 6 years to follow each cohort for 3 school years. One teacher left the study during the first month because of personal reasons, thereby withdrawing students in her class. In the remaining 119 classrooms, we screened 2,023 students, for whom we had consent, using the *Test of Computational Fluency* (Fuchs, Hamlett, & Fuchs, 1990). To obtain a representative sample, we randomly sampled 1,320 students, blocking within classroom and so that 25% had scores 1 standard deviation (*SD*) below the mean of the distribution, 50% had scores within 1 *SD* of the mean of the distribution, and 25% had scores 1 *SD* above the mean of the distribution. We excluded students with a standard score of less than 80 on both subtests of the two-subtest *Wechsler Abbreviated Scale of Intelligence* (WASI; Wechsler, 1999) because our focus was LD, not mental retardation.

In September and October of third grade, we assessed these 1,320 students on a battery of cognitive measures. We also followed these students' academic development, sampling performance on reading comprehension using *Woodcock Reading Mastery Tests* (WRMT; Woodcock, 1998) Passage Comprehension on three occasions (spring of third, fourth, and fifth grades), on word reading using the *Wide Range Achievement Test 3* (WRAT; Wilkinson, 1993) Reading on four occasions (September and March of third grade and spring of fourth and fifth grades), on applied problems using *Woodcock–Johnson III* (WJ-III; Woodcock, McGrew, & Mather, 2001) Applied Problems on four occasions (September and March of third grade and spring of fourth and fifth grades), and on calculations (WRAT Arithmetic) on four occasions (September and March of third grade and in spring of fourth and fifth grades). We then excluded all Cohort 1 students (because we first began collecting reading comprehension data in spring of third grade with Cohort 2) as well as students for whom we did not have at least three measurement occasions in each academic area (we needed at least three data points to model academic development).

This left 684 students who, across the three school years, had participated in 485 classrooms. Based on the tests' norms, mean performance for this sample was 49.31 on the WASI Matrix Reasoning (*SD* = 10.57), 96.60 on WJ-III Visual Matching (*SD* = 15.51), 91.93 on WJ-III Concept Formation (*SD* = 13.47), 96.94 on *Woodcock Diagnostic Reading Battery* (WDRB; Woodcock, 1997) Listening Comprehension (*SD* = 18.56), 85.24 on *Test of Language Development* (TOLD; Newcomer & Hammill, 1988) Grammatic Closure (*SD* = 10.88), 46.51 on WASI Vocabulary (*SD* = 9.68), 93.64 on *Working Memory Test Battery for Children* (WMTB-C; Pickering & Gathercole, 2001) Listening Recall (*SD* = 15,44), and 96.54 on WJ-III Numbers Reversed (*SD* = 14.25). Of these 684 students, 345 (50.4%) were male, 415 (60.7%) received subsidized lunch, 297 (43.4%) were African American, 257 (37.6%) were European American, 86 (12.6%) were Hispanic, 44 (6.4%) were Other, and 32 (4.7%) were English language learners (ELLs).

Measures

Cognitive dimensions. *Nonverbal problem solving* was measured with Matrix Reasoning (Wechsler, 1999) with four types of tasks: pattern completion, classification, analogy, and serial reasoning. Examinees look at a matrix from which a section is missing and complete the matrix by saying the number of or pointing to one of the five response options. Examinees earn points by identifying the correct missing piece of the matrix. Testing is discontinued after four errors on five consecutive items or four consecutive errors. The score is the number of correct responses. As reported by the test developer, reliability is .94 for 8-year-olds; the correlation with the *Wechsler Intelligence Scale for Children–III* (WISC-III) Full Scale IQ is .66. Coefficient alpha (N = 1,302) was .78.

Processing speed was measured with WJ-III Visual Matching (Woodcock et al., 2001), which asks examinees to locate and circle two identical numbers in rows of six numbers. Examinees have 3 min to complete 60 rows and earn credit by correctly circling the matching numbers in each row. As reported by the test developer, reliability is .91 for 8-year-olds.

Concept formation was assessed with WJ-III Concept Formation (Woodcock et al., 2001), which asks examinees to identify the rules for concepts when shown illustrations of instances and noninstances of the concept. Examinees earn credit by correctly identifying the rule that governs each concept. Cutoff points determine the ceiling. The score is the number of correct responses. As reported by the test developer, reliability is .93 for 8-year-olds.

Language was assessed with three measures. TOLD Grammatic Closure (Newcomer & Hammill, 1988) measures the ability to recognize, understand, and use English morphological forms. The examiner reads 30 sentences, one at a time; each sentence has a missing word. Examinees earn 1 point for each sentence correctly completed. As reported by the test developers, reliability is .88 for 8-year-olds; the correlation with the *Illinois Test of Psycholinguistic Abilityies* Grammatic Closure is .88 for 8-year-olds. Coefficient alpha on this sample was .78. The WDRB Listening Comprehension (Woodcock, 1997) measures the ability to understand sentences or passages. With 38 items, students supply the word missing from the end of each sentence or passage. The test begins with simple verbal analogies and associations and progresses to comprehension involving the ability to discern implications. Testing is discontinued after six consecutive errors. The score is the number of correct responses. As reported by the test developers, reliability is .80 at ages 5 to 18. Coefficient alpha on this sample was .84. Vocabulary (Wechsler, 1999) measures expressive vocabulary, verbal knowledge, and foundation of information with 42 items. The first four items present pictures; the student identifies the object in the picture. For the remaining items, the tester says a word that the student defines. Responses are awarded a score 0, 1, or 2 depending on quality. Testing is discontinued after five consecutive scores of 0. The score is the total number of points. As reported by Zhu (1999), split-half reliability is .86 to .87 at ages 6 to 7; the correlation with the WISC-III Full Scale IQ is .72. Coefficient alpha on this sample was .74. We created weighted composite variables, using a principal components factor analysis (which yielded only one factor), across these three language variables.

Working memory was assessed with two measures. WMTB-C Listening Recall (Pickering & Gathercole, 2001) measures verbal working memory; the tester says a series of short sentences, only some of which make sense. The student indicates whether each sentence is true or false. After all sentences in a trial (i.e., 1–6 sentences) are heard and determined to be true or false, the student recalls the final word of each sentence in the order presented. The student earns 1 point for each sequence of final words recalled correctly in the right order, and the score is the total of correct sequences. Testing is discontinued when the student makes three or more errors in any block of items. As reported by the test authors, test–retest reliability is .93. Coefficient alpha (N = 1,302) was .75. With WJ-III Numbers Reversed (Woodcock et al., 2001), a measure of numerical working memory, the tester says a string of random numbers; the student says the series backward. Item difficulty increases as more numbers are added to the series. Students earn credit by repeating the numbers correctly in the opposite order. As reported by the test developers, reliability is .86 for 8-year-olds. Coefficient alpha on this sample was .86. We created weighted composite variables, using a principal components factor analysis (which yielded only one factor), across these two working memory variables.

Achievement. *Reading comprehension* was assessed with WRMT Passage Comprehension (Woodcock, 1998). This is a norm-referenced, modified cloze procedure. For the first set of items, the tester presents a symbol, or rebus, and asks the child to point to the picture corresponding to the rebus. Next, the child is asked to point to the picture representing words printed on the page. In later items, the child reads a passage silently to identify the missing word in the passage. Split-half reliability was .90 on this sample. *Word reading* was assessed with WRAT Reading (Wilkinson, 1993), where students read aloud letters and words until a ceiling is reached. Coefficient alpha on this sample was .89. *Applied problems* was assessed with WJ-III Applied Problems (Woodcock et al., 2001), which measures skill in analyzing and solving practical math problems with 60 items. The tester orally presents items involving counting, telling time or temperature, and problem solving. Testing is discontinued after six consecutive errors. The score is the number of correct items. As reported by the test developer, the 1-year test–retest reliability is .85; the ratio of true score variance to observed variance is .88 to .91. Coefficient alpha on this sample was .90. *Calculations* was assessed with WRAT Arithmetic (Wilkinson, 1993), where students have 10 min to complete calculation problems of increasing difficulty. Coefficient alpha on this sample was .91.

Procedure

Data on the five cognitive dimensions were collected individually in September and October of third grade during two 45-min sessions. Data on the academic measures were collected individually for reading comprehension on three occasions (beginning in the spring of third grade), individually for word reading on four occasions, individually for applied problems on four occasions, and in groups for calculations on four occasions. Tests were administered by trained examiners, each of whom had demonstrated 100% accuracy during mock administrations. All individual sessions were audiotaped, and 19.7% of tapes, distributed equally across testers, were selected randomly for accuracy checks by an independent scorer. Interscorer agreement was 98.9.

Data Analysis and Results

Overlap Between Reading and Mathematics LD

We designated LD based on final status. To derive final status, we estimated an intercept for each student, within each academic area, by applying ordinary least squares regression to all available testing occasions on that academic area measure. Growth modeling was used to improve the overall reliability of the estimated final intercept and to take advantage of all student data across the years. We had at least three measurements on each student. (Even if the last point is missing, intercept estimated from three points provides an endpoint estimate comparable to one based on all available data, as per Singer and Willett (2003). Each student's individual linear regression model was in the form of Score = $\beta_0 + \beta_1 \times$ Time, where β_0 was the intercept and β_1 was the student's individual slope per year, both expressed in standard score points on the tests' normative frameworks. To make the intercept represent the student's endpoint, we defined Time 0 as the spring of fifth grade measurement occasion.

We designated LD for each academic area separately by reformulating LD and NLD groups for each academic outcome: reading comprehension, word reading, applied problems, and calculations. In each academic area, on final (spring of fifth grade) intercept, students who scored above the 39th percentile were designated NLD; students who scored below the 15th percentile were designated LD. We selected the 15th percentile because it is useful for understanding LD as practiced in the schools. The percentage of students with LD was 8.5 for reading comprehension, 10.4 for word reading, 8.2 for applied problems, and for 13.9 for calculations.

To examine the overlap between reading and mathematics LD, we designated students in the buffer zone as NLD. Including the buffer zone students in the overlap analyses allowed us to use the entire sample of students to more accurately estimate the percentage of overlap in reading comprehension and applied problem LD and in word reading and calculation LD. We first considered the extent to which students shared LD across higher order skills (reading comprehension vs. applied problems). On higher order skills, 96 students were identified as LD: 18 (18.8%) on reading comprehension and applied problems, 40 (41.7%) on only reading comprehension, and 38 (39.6%) on only applied problems. We then considered the extent to which students shared LD across the lower-order skills (word reading vs. calculations). On lower-order skills, 140 students were identified as LD: 26 (18.6%) on word reading and calculations, 45 (32.1%) only on word reading, and 69 (49.3%) only on calculations.

Sociodemographic Patterns, Cognitive Profiles, and Academic Profiles

We examined the sociodemographic patterns, the cognitive profiles, and the academic profiles associated with LD. This series of analyses was conducted separately for reading comprehension LD, for word reading LD, for applied problems LD, and for calculations LD. So when considering who is LD or NLD on reading comprehension, we excluded 270 students in the reading comprehension buffer zone (i.e., final intercept estimates on reading comprehension that fall between the 15th and 39th percentile); when considering applied problems final status LD, we excluded 152 students in that LD designation's buffer zone; and so on. See Table 1 for means, *SD*s, and effect sizes (ESs; difference in means divided by the *SD* of the NLD group) on WASI IQ (standard scores, $M = 100$, $SD = 15$, relative to the test's norms), cognitive dimensions (all expressed as *T*-scores, $M = 50$, $SD = 10$, relative to a local norm group of 1,302 students; see below), and achievement data (slope and final intercept expressed in standard score units as per the tests' norms) and for percentages on sociodemographic variables as a function of reading comprehension LD status and as a function of word reading LD status. See Table 2 for parallel data as a function of applied problems LD status and as a function of calculations LD status.

Demographic patterns. The relation between sex and LD status was significant only for reading comprehension LD, $\chi^2(1, N = 414) = 5.48$, $p = .019$, where males were significantly more likely to be designated LD. No other effect was significant: $\chi^2(1, N = 534) = 0.02$, $p = .899$ for word reading LD; $\chi^2(1, N = 532) = 0.20$, $p = .655$ for applied problems LD; and $\chi^2(1, N = 569) = 0.17$, $p = .683$ for calculations LD.

For proportion of subsidized lunch, students with LD were more likely to receive subsidized lunch than were NLD students, regardless of academic area: $\chi^2(1, N = 414) = 13.98$, $p < .001$ for reading comprehension LD; $\chi^2(1, N = 534) = 6.08$, $p = .014$ for word reading LD; $\chi^2(1, N = 532) = 5.48$, $p = .019$ for applied problems LD; and $\chi^2(1, N = 569) = 9.62$, $p = .002$ for calculations LD.

Given the established relation between poverty and ethnicity, we expected a similar pattern of results across both sociodemographic variables, and consistency did exist for three LD variables: $\chi^2(3, N = 414) = 12.12$, $p = .007$ for reading comprehension LD; $\chi^2(3, N = 532) = 23.48$, $p < .001$ for applied problems LD; and $\chi^2(3, N = 550) = 10.73$, $p = .013$ for calculations LD. LD students were consistently more likely to be African American and less likely to be Other (largely Kurdish or Asian). Otherwise, the pattern varied: For reading comprehension LD, students were less likely to be European American but comparably likely to be Hispanic; for applied problems, students with LD were

Table 1. IQ, Cognitive Dimensions, Achievement Data, and Demographics by Reading Disability Status (N = 684)

	Reading Comprehension							Word Reading						
	LD (n = 58)			NLD (n = 356)				LD (n = 71)			NLD (n = 463)			
Variable	M	SD	%	M	SD	%	ES[a]	M	SD	%	M	SD	%	ES[a]
IQ	85.37	8.45		103.02	12.84		1.37	89.44	10.23		100.37	13.01		0.84
Cognitive dimension														
Nonverbal PS	44.59	7.99		53.31	9.25		—	48.13	8.66		51.97	9.97		—
Processing speed	44.74	10.18		50.58	9.91		—	46.79	9.90		49.62	10.56		—
Concept formation	43.37	7.84		52.94	10.08		—	46.03	7.86		51.14	10.45		—
Language	40.91	7.83		54.75	8.49		—	44.33	8.42		52.33	9.25		—
Working memory	43.89	8.22		53.64	8.64		—	43.87	7.41		52.63	9.07		—
Reading comprehension														
Slope	–2.48	3.00		1.75	4.12		1.02	0.93	5.01		0.52	3.70		–0.11
Intercept	79.67	4.41		103.69	6.57		1.02	86.71	9.53		99.93	8.29		1.59
Word reading														
Slope	–0.11	3.12		0.74	3.55		0.24	–2.68	3.87		1.30	3.34		1.19
Intercept	86.28	9.44		108.19	10.82		2.02	79.56	4.57		109.23	8.64		3.41
Applied problems														
Slope	–1.71	3.09		–1.36	3.77		0.08	–1.18	3.70		–1.42	3.70		–0.06
Intercept	88.31	9.56		107.25	9.64		1.96	92.15	10.01		104.81	10.69		1.18
Calculations														
Slope	–1.14	5.17		0.44	4.49		0.36	–0.10	5.17		0.34	4.36		0.10
Intercept	88.57	12.60		105.51	11.95		1.42	89.79	13.24		104.19	12.14		1.35
Gender: Male			62.1			45.5				49.3			50.1	
Subsidized lunch			75.9			49.4				70.4			54.9	
Ethnicity: AA			58.6			35.7				50.7			37.6	
EA			25.9			45.5				36.6			41.7	
Hispanic			12.1			12.1				9.9			13.6	
Other			3.4			6.7				2.8			7.1	
ELL[b]			1.7			5.3				5.6			5.0	

Note: IQ is based on two–subtest *Wechsler Abbreviated Scale of Intelligence* (WASI); cognitive dimension scores are T-scores (M = 50, SD = 10) based on local norm (N = 1,302); nonverbal PS is nonverbal problem solving based on WASI matrix reasoning; processing speed is *Woodcock–Johnson III* (WJ-III) Visual Matching; concept formation is WJ-III Concept Formation; language is a factor score on *Woodcock Diagnostic Reading Battery* Listening Comprehension, WASI Vocabulary, and *Test of Language Development* Grammatic Closure; working memory is a factor score on *Working Memory Test Battery for Children* Listening Recall and WJ-III Numbers Reversed; applied problems is WJ-III Applied Problems; reading comprehension is *Woodcock Reading Mastery Tests-R/NU* Passage Comprehension; calculations is *Wide Range Achievement Test 3* (WRAT) Arithmetic; word reading is WRAT Reading; AA is African American; EU is European American; LD is learning disability; and NLD is no learning disability.
[a]ES is Cohen's d for continuous variables.
[b]English language learner is at the beginning of third grade.

less likely to be European American and Hispanic; and for calculations, students with similarly likely to be European American and Hispanic. Even so, for word reading LD, despite a significant relation with subsidized lunch, the relation with ethnicity was not significant, $\chi^2(3, N = 534) = 5.49$, $p = .139$.

For ELL status, the relation with LD status was not significant: $\chi^2(1, N = 414) = 1.42$, $p = .234$ for reading comprehension LD; $\chi^2(1, N = 534) = 0.06$, $p = .811$ for word reading LD; $\chi^2(1, N = 532) = 2.96$, $p = .086$ for applied problems LD; and $\chi^2(1, N = 569) = 3.02$, $p = .082$ for calculations LD.

Cognitive profiles. We assessed whether the profiles of LD versus NLD students had a distinctive shape on the five cognitive dimensions we measured at the beginning of third grade. Profile analysis requires a common normative reference group across cognitive dimensions, for which we relied on the 1,302 students on whom we had complete data on these five cognitive dimensions at the beginning of third grade. Based on the tests' norms, mean performance for these 1,302 students was a T-score of 48.79 on WASI (Wechsler, 1999) Matrix Reasoning (SD = 11.01), a standard score of 97.74 on WJ-III Visual Matching (SD = 15.68), a standard score of 92.44 on WJ-III Concept Formation (SD = 13.49), a standard score of 96.71

Table 2. IQ, Cognitive Dimensions, Achievement Data, and Demographics by Mathematics LD Status (*N* = 684)

	Applied Problems							Calculations						
	LD (*n* = 56)			NLD (*n* = 476)				LD (*n* = 32)			NLD (*n* = 537)			
Variable	*M*	*SD*	%	*M*	*SD*	%	ES[a]	*M*	*SD*	%	*M*	*SD*	%	ES[a]
IQ	83.82	7.67		100.81	12.89		1.32	88.12	10.38		100.34	13.25		0.92
Cognitive dimension														
Nonverbal PS	42.39	7.17		52.78	9.12		—	45.64	8.72		52.37	9.43		—
Processing speed	44.83	9.48		50.52	10.02		—	44.12	10.65		50.67	9.99		—
Concept formation	40.56	5.55		52.16	10.01		—	45.09	8.10		51.67	10.48		—
Language	41.63	9.42		52.29	9.26		—	45.43	8.74		51.65	9.52		—
Working memory	44.25	8.20		52.46	9.07		—	44.87	8.42		52.47	8.99		—
Reading comprehension														
Slope	–0.83	3.36		0.81	8.10		0.43	0.08	4.47		0.53	3.91		0.12
Intercept	86.83	7.93		99.66	3.81		1.50	90.03	9.46		99.21	8.97		1.02
Word reading														
Slope	–0.08	3.35		0.51	3.72		0.16	–0.21	3.70		0.57	3.65		0.21
Intercept	92.02	11.16		105.56	12.19		1.11	92.28	11.59		105.96	12.18		1.12
Applied problems														
Slope	–3.58	2.31		–0.84	3.65		0.75	–1.67	3.66		–1.02	3.61		0.13
Intercept	79.76	4.62		107.79	7.44		2.77	88.85	10.13		106.56	9.22		1.92
Calculations														
Slope	–1.78	4.47		0.64	4.33		0.55	–5.49	4.18		1.60	3.74		1.90
Intercept	83.55	10.22		105.85	10.60		2.10	77.71	6.27		108.27	7.83		3.90
Gender: Male			53.6			50.4				52.3			50.3	
Subsidized lunch			71.4			55.0				72.6			55.4	
Ethnicity: AA			69.6			36.3				54.7			40.0	
EA			21.4			41.8				33.7			38.2	
Hispanic			7.1			14.3				10.5			13.6	
Other			1.8			7.6				1.0			8.1	
ELL[b]			0.0			8.9				1.1			5.1	

Note: IQ is based on two–subtest *Wechsler Abbreviated Scale of Intelligence* (WASI); cognitive dimension scores are *T*-scores (*M* = 50, *SD* = 10) based on local norm (*N* = 1,302); nonverbal PS is nonverbal problem solving based on WASI matrix reasoning; processing speed is *Woodcock–Johnson III* (WJ-III) Visual Matching; concept formation is WJ-III Concept Formation; language is a factor score on *Woodcock Diagnostic Reading Battery* Listening Comprehension, WASI Vocabulary, and *Test of Language Development* Grammatic Closure; working memory is a factor score on *Working Memory Test Battery for Children* Listening Recall and WJ-III Numbers Reversed; applied problems is WJ-III Applied Problems; reading comprehension is *Woodcock Reading Mastery Tests-R/NU* Passage Comprehension; calculations is *Wide Range Achievement Test 3* (WRAT) Arithmetic; word reading is WRAT Reading; AA is African American; EU is European American; LD is learning disability; and NLD is no learning disability.
[a]ES is Cohen's d for continuous variables; pbi coefficient for demographics (computed as EA vs. all other categories for race).
[b]English language learner is at the beginning of third grade.

on WDRB Listening Comprehension (*SD* = 18.14), a standard score of 85.49 on TOLD Grammatic Closure (*SD* = 11.08), a *T*-score of 46.59 on WASI Vocabulary (*SD* = 9.93), a standard score of 92.82 on WMTB-C Listening Recall (*SD* = 16.06), and a standard score of 95.71 on WJ-III Numbers Reversed (*SD* = 14.50). Of these 1,302 students, 567 (49.6%) were male, 735 (56.5%) received subsidized lunch, 563 (43.2%) were African American, 520 (39.9%) were European American, 129 (9.9%) were Hispanic, 90 (7.0%) were Other, and 44 (3.4%) were ELLs. In creating the common normative framework, we expressed scores as *T*-scores (*M* = 50, *SD* = 10) for each of five cognitive dimensions.

For each cognitive variable (i.e., separately for reading comprehension LD, for word reading LD, for applied problems LD, and for calculations LD), our first step in the cognitive profile analysis was to conduct a two-way ANOVA. For each of the four LD status variables, the between-subjects factor was LD status (0, 1) and the within-subjects factor was cognitive dimension (1–5): *T*-score (based on the local normative of 1,302) on nonverbal problem solving versus processing speed versus concept formation versus language versus working memory. The main effect for LD, referred to as the *elevation* effect, represents differences between LD and NLD students averaged across the cognitive dimensions.

Table 3. Cognitive Dimension Profiles by Learning Disability Status

	NLD		LD					
Cognitive Dimension	*M*	*SD*	*M*	*SD*	Effect Size	Prob Raw	Prob Boot	Diff Zero
Reading comprehension LD								
Nonverbal PS	–0.11	9.25	0.66	8.06	0.08	.55	.98	.53
Processing speed	–0.50	9.91	3.04	10.19	0.36	.01	.06	.03
Concept form	–0.01	10.08	0.03	7.85	0.00	.98	1.00	.97
Language	0.58	8.49	–3.58	8.18	–0.49	.001	.003	.002
WM	0.03	8.64	–0.16	8.27	–0.02	.88	1.00	.88
Word reading LD								
Nonverbal PS	–0.25	9.58	1.62	8.66	0.20	.12	.43	.12
Processing speed	–0.38	10.56	2.49	9.90	0.27	.03	.14	.04
Concept form	–0.08	10.45	0.52	7.86	0.06	.64	.99	.58
Language	0.30	9.25	–1.99	8.42	–0.25	.05	.20	.051
WM	0.41	9.07	–2.64	7.41	–0.34	.01	.03	.004
Applied problems LD								
Nonverbal PS	0.11	9.12	–0.97	7.17	–0.12	.39	.90	.32
Processing speed	–0.38	10.02	3.24	9.48	0.36	.01	.05	.01
Concept form	0.24	10.01	–2.05	5.55	–0.23	.09	.36	.01
Language	0.14	9.26	–1.21	9.42	–0.15	.30	.81	.34
WM	–0.12	9.04	0.99	8.20	0.12	.38	.89	.37

Note: NLD is not learning disabled; LD is learning disabled; *SD* is standard deviation; effect size is in standard deviations; prob raw is unprotected *t* test; prob boot is bootstrap test controlling for five tests; diff zero is difference from zero for LD; nonverbal PS is nonverbal problem solving; WM is working memory.

The main effect for cognitive dimension, referred to as the *flatness* effect, represents differences among cognitive dimensions averaged across the LD and NLD students. The five cognitive dimension scores were scaled to have means close to 50 (range = 48.90–50.47). Within profile analysis, the interaction between LD status and cognitive dimension, referred to the *shape* effect, is of interest. In three of four academic areas, these interactions (which supersede main effects) were significant: for reading comprehension LD, $F(4, 2060) = 4.5$, $p < .001$; for word reading LD, $F(4, 2660) = 4.4$, $p < .001$; for applied problems LD, $F(4, 2650) = 3.2$, $p = .012$; and for calculations LD, $F(4, 2740) = 0.20$, $p < .920$.

To describe the shape effect, it is necessary to remove the main effects of elevation and cognitive dimension (Bernstein, Garbin, & Teng, 1988; Fletcher et al., 1994). Toward this end, we subtracted the grand mean across the two main effects from each individual's cognitive dimension score, thereby reducing the mean elevation of each group's residual score to zero. Any variation among group means on the resulting residual scores for the cognitive dimensions is then entirely the result of the shape effect (i.e., the LD status by cognitive dimension interaction profile).

To examine the significant shape effects, we then conducted traditional MANOVA-based profile analysis (Tabachnick & Fidell, 2007) for each of the three LD variables where the shape effect was significant. In the MANOVA model, Y is a vector of five continuous cognitive dimensions; *X* is LD (0 = NLD, 1 = LD): $[\beta_1 Y_1\ \beta_2 Y_2\ \beta_3 Y_3\ \beta_4 Y_4\ \beta_5 Y_5] = F(X) = F(\text{LD } 01)$. In this model, five cognitive dimensions are a function of LD status. The MANOVA finds the best combination of betas β_1 to β_5 to discriminate the different profiles of the LD and NLD groups. Because the main effect has been removed from the residual scores, the shape effect betas have mixed signs: some positive and others negative.

Means for the three profile analyses (for which the shape effect was significant) appear in Table 3 (see Figure 1 for plots). Each profile shows five rows (one for the residual score on each of the five cognitive dimensions) and eight columns. Columns 1 through 4 provide means and *SD*s for the NLD and LD groups. In column 5, the differences between the LD and NLD groups are shown as ESs, where $\text{ES} = (M_{\text{LD}} - M_{\text{NLD}})/SD_{\text{NLD}}$ (Glass, 2006). For each of the three LD variables, profile means for NLD students are near 50 with a *SD* of 10, approximately flat; and therefore residualized mean performance was near zero. By contrast, the residuals for the LD students are much larger, with positive or negative values but still summing to zero across the five cognitive measures. This profile shape shows the LD status by cognitive dimension interaction.

Columns 6 and 7 show *t* test probabilities for differences between the LD and NLD groups. Column 6 is the traditional unprotected student's *t*; column 7 is a bootstrap resampling (Efron, 1982) *t* test that exacts a penalty for conducting five tests. This penalty keeps the family-wise probability of false

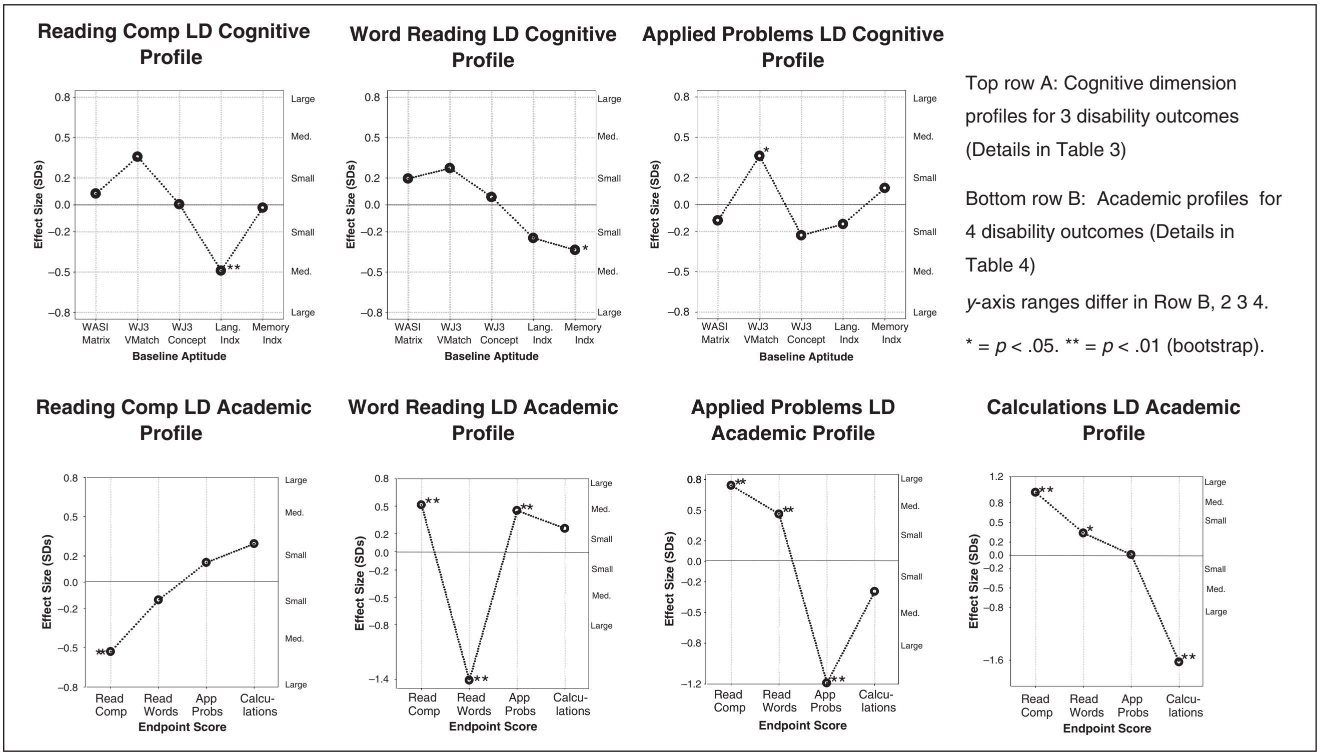

Figure 1. Cognitive and academic profiles by learning disability (LD) status

results (Benjamini & Hochberg, 1995; Hochberg, 1988) at 5%. The correction was done with SAS PROC MULTTEST (Westfall, Tobias, Rom, Wolfinger, & Hochberg, 1999) using 100,000 bootstrap resamples. Unlike the underpowered Bonferroni correction, the bootstrap does not rely on the false assumption that the five cognitive dimensions are uncorrelated. Finally, column 8 represents (the difference test expressed in the form of a p value) whether the absolute value of the mean score for each of the measures, within the LD group only, is significantly greater than zero. Given that the expected value of the mean score is zero for each measure within the LD groups, we used this test to identify areas of relative strength and weakness within the various LD subtypes.

A traditional profile analysis (Tabachnick & Fidell, 2007) uses MANOVA to find the function that best discriminates between NLD and LD groups. This canonical discriminate function has an intercept and five βs for the five profile variables. Like the ESs, these coefficients describe the LD status by cognitive dimension profile. The canonical βs were, however, always proportional to the ESs, suggesting that they describe the same profile in different units. We chose a single ES plot (see Figure 1) because ES is intuitive to most researchers as the difference between means in *SD* units.

As shown in Table 3, students with reading comprehension LD were low relative to their other cognitive abilities on language (ES = –0.49), with relative strength on processing speed (ES = 0.36). Children with word reading LD were low relative to their other cognitive abilities on working memory and language (ES = –0.34 and –0.25), with relative strength on processing speed (ES = 0.27). Children with applied problems LD were low relative to the other cognitive dimensions on concept formation (ES = –0.23), with relative strength on processing speed (ES = 0.36).

Academic profiles. We also examined whether the profiles of LD versus NLD students had a distinctive shape in the four final intercept (end of fifth grade) achievement areas. Because profile analysis requires a common normative reference group across cognitive dimensions and because the tests we used to index achievement in the four academic areas did not use the same national sample for norming (i.e., we used WJ-III for reading comprehension and applied problems, WRAT for word reading and calculations), we did the following only for the purpose of examining the academic profiles (i.e., when we used these achievement tests for designating LD versus NLD, we used the tests' norms based on their national samples). For each of the four academic areas separately, on each measurement occasion separately, we transformed raw scores for the 684 students in the sample into T-scores. Then, using the series of T-scores within a given academic area separately, we applied ordinary least squares regression to all available testing occasions for children with three or four measurements

Table 4. Academic Dimension Profiles by Learning Disability Status

	NLD		LD					
Academic Dimension	*M*	*SD*	*M*	*SD*	Effect Size	Prob Raw	Prob Boot	Diff Zero
Reading comp LD								
Read comp	0.49	6.57	–3.00	4.42	–0.53	.0001	.001	<.0001
Word read	0.21	10.82	–1.26	9.44	–0.14	.33	.75	.31
Applied probs	–0.20	9.64	1.24	9.64	0.15	.29	.70	.33
Calculations	–0.49	11.95	3.02	12.60	0.29	.04	.14	.07
Word reading LD								
Read comp	–0.57	8.29	3.70	9.53	0.51	<.0001	.0004	.002
Word read	1.62	8.64	–10.56	4.57	–1.41	<.0001	<.0001	<.0001
Applied probs	–0.64	10.69	4.19	10.01	0.45	.0004	.001	.001
Calculations	–0.41	12.14	2.68	13.24	0.25	.049	.16	.09
Applied problems LD								
Read comp	–0.67	8.54	5.67	7.93	0.74	<.0001	<.0001	<.0001
Word read	–0.59	12.19	5.05	11.16	0.46	.001	.004	.001
Applied probs	0.93	7.44	–7.92	4.62	–1.19	<.0001	<.0001	<.0001
Calculations	0.33	10.60	–2.80	10.23	–0.30	.04	.12	.045
Calculations LD								
Read comp	–1.49	8.97	7.12	9.46	0.96	<.0001	<.0001	<.0001
Word read	–0.71	12.18	3.40	11.56	0.34	.003	.01	.01
Applied probs	–0.01	9.22	0.06	10.13	0.01	.95	1.00	.96
Calculations	2.21	7.83	–10.57	6.27	–1.63	<.0001	<.0001	<.0001

Note: NLD is not learning disabled; LD is learning disabled; *SD* is standard deviation; effect size is in standard deviations; prob raw is unprotected *t* test; prob boot is bootstrap test controlling for five tests; diff zero is difference from zero for LD.

(having three or four measurements suffice and made imputation of missing waves unnecessary), centering at the spring of fifth grade assessment, as mentioned previously.

The profile analysis conducted on the four academic final intercepts followed the methods already described for the cognitive dimensions profile analyses. For each LD variable (i.e., separately for reading comprehension LD, for word reading LD, for applied problems LD, and for calculations LD), our first step in the academic profile analysis was to conduct a two-way ANOVA. For each of the four LD variables, the between-subjects factor was LD status and the within-subjects factor was academic dimension (normative sample of 684 *T*-score final intercept on reading comprehension vs. final intercept on word reading vs. final intercept on applied problems vs. final intercept on calculations). For all four LD variables, the LD status by academic area interaction was significant: for reading comprehension LD, $F(7, 1655) = 14.9$, $p < .001$; for word reading LD, $F(6, 2135) = 13.5$, $p < .001$; for applied problems LD, $F(7, 2127) = 8.6$, $p < .001$; and for calculations LD, $F(7, 2199) = 17.4$, $p < .001$.

We then conducted MANOVA-based profile analyses using methods described earlier. Means and other statistics from the four profile analyses appear in Table 4, with ES plots shown in Figure 1. The plots highlight ES standards for Cohen's (1988) *d* (small, medium, large ≈ .2, .5, .8, respectively). The profile for each LD variable has four rows, one for the final intercept on each of the four academic areas. As before, we present means and *SD*s for the LD and NLD groups and plot the ES between the two groups to show the shapes of each profile. Significance tests appear in columns 6 through 8, and the bootstrap significance appears as asterisks in the profile charts (see Figure 1).

As shown in Table 4, for each of the four LD variables, profile residualized means for NLD students are near zero, approximately flat. By contrast, the residuals for the LD students are larger, with positive or negative values. Again the expected value of the mean score is zero for each measure within the LD groups; therefore, we used the difference test to identify areas of relative strength and weakness within the various LD subtypes. Children with reading comprehension LD were low relative to the other academic areas on reading comprehension (ES = –0.53), with relative strength on calculations (ES = 0.29). Children with word reading LD were low relative to the other academic areas on word reading (ES = –1.41), with relative strength on applied problems and reading comprehension (ES = 0.45 and 0.51). Children with applied problems LD were low relative to the other academic areas on applied problems and calculations (ES = –1.19 and –0.30), with relative strength on reading comprehension and word reading (ES = 0.74 and 0.46). Children with calculations LD were low relative to the other academic areas on calculations (ES = −1.63), with relative strength on reading comprehension and word reading (ES = 0.96 and 0.34).

Discussion

In the present study, we extended prior work on the cognitive profiles of LD in reading and mathematics by focusing on the intermediate grades, by considering four academic domains that include higher and lower order skills, by taking a developmental approach to consider how cognitive dimensions at the beginning of third grade support development through the end of fifth grade, and by formally conducting academic as well as cognitive multivariate profile analysis. We began by exploring the extent to which demographic patterns recur in the various forms of LD. Except for sex, which was associated only with reading comprehension LD (i.e., more males experienced reading comprehension LD), demographic patterns were largely similar across LD in the four academic areas. There was no association between ELL and LD in any academic domain; across all four academic areas, LD was associated with subsidized lunch status and racial/ethnic background; and for three academic areas (all but word reading), race/ethnicity was related to LD status, with a greater proportion of African American students experiencing the severe academic underachievement associated with LD. The patterns of subsidized lunch and race associated with LD suggest the deleterious role poverty can play in determining academic competence.

These demographic patterns aside, however, results generally provide support for the specificity hypothesis, in which the unexpected underachievement associated with LD is conceptualized in terms of distinctive patterns of cognitive and academic strengths and weaknesses. A notable exception was the cognitive profile of students with calculations LD. Based on prior work, we had hypothesized that students with calculations LD would manifest a distinctive profile characterized by specific deficits in processing speed (e.g., Bull & Johnston, l997; Fuchs et al., 2005; Geary et al., 2006; Hecht et al., 2001) and working memory (Barrouillet et al., 1997; Engle et al., 1999; Geary et al., 2007; Swanson & Beebe-Frankenberger, 2004). By contrast, results demonstrated that performance on the five cognitive dimensions was similarly flat for students with and without LD. It is possible that calculation skill from third through fifth grade, which is complicated by the introduction of rational numbers, may alter the salient cognitive underpinnings of development (see Hecht, in press), which we failed to consider. Future work may provide greater insight by separating measures of whole number and rational number calculation skills and assessing a broader set of cognitive dimensions.

Although there was no distinctive cognitive profile associated with calculations LD, distinctive patterns of cognitive strengths and weaknesses did emerge for the other three LD areas. Moreover, a distinctive pattern of academic strengths and weaknesses was identified in all four LD areas. Readers should note that where we consider effects that only approach significance, we note this by including the *p* value. We chose to include effects that approach significance given the small sample sizes of the LD groups, which undermine statistical power. To avoid this limitation, future studies should include larger representative samples to yield larger sample sizes for the LD groups.

In terms of cognitive profiles, whereas NLD students manifested a flat pattern of performance across cognitive dimensions, students with reading comprehension LD were low relative to their other cognitive abilities on language, a composite variable that included listening comprehension, oral vocabulary, and syntax. This finding corroborates earlier studies demonstrating the role these oral language abilities play in reading comprehension (e.g., Catts et al., 2001; Dickinson et al., 2003; Leach et al., 2003; McCardle et al., 2001; Muter et al., 2004; Nation et al., 2001; Nation & Snowling, 1998, 1999; Oakhill et al., 2003; Scarborough, 2005; Sénéchal et al., 2006). More surprisingly, in contrast to NLD students who manifested a flat pattern of performance across cognitive dimensions, students with word reading LD were low relative to other cognitive abilities on working memory and oral language ($p = .051$). It is possible that multisyllabic word identification, as required on the word reading measure at the end of fifth grade, taps more sophisticated oral language abilities than does earlier word-level skills. Support for this can be found in the adult literature on multisyllabic word reading where semantic properties of words independently predict accuracy and latency of pronunciations above and beyond word length, phonological properties, and other word-level features (see Balota, Yap, Cortese, 2006; Yap & Balota, 2009). In addition, new evidence from behavioral and neuroimaging studies implicates working memory deficits in children and adults with developmental dyslexia (e.g., Beneventi, Tønnessen, Ersland, & Hugdahl, 2010; Berninger, Raskind, Richards, Abbott, & Stock, 2008; Smith-Spark & Fisk, 2007) that affect word reading ability (Berninger et al., 2006). So although working memory is not frequently identified as a salient predictor of word-level reading skill in the earlier grades, it is possible that this cognitive ability relates better to multisyllabic word-level skills as reflected at the end of fifth grade. Decoding of multisyllabic words appears to require students to hold associations between letters and sounds while building subsequent associations and tying the series together into a word, and Conners et al. (2001) demonstrated such a relation in 8- to 12-year-olds. In terms of applied problems LD profile analysis revealed low performance on concept formation relative to other cognitive dimensions (whereas the performance of NLD students was flat across cognitive dimensions), and concept formation has been associated in previous work with word-problem skills at third grade (e.g., Fuchs et al., 2008).

For each of these three LD categories, the distinctive cognitive strength was processing speed. We offer two competing hypotheses of how processing speed interacts with the other cognitive processes to affect academic performance. The first posits that this relative strength on processing speed mitigates the cognitive difficulties that undermine academic competence, making their deficits in the reading comprehension, word reading, or applied problems content tapped by the end of fifth grade less severe than would otherwise be. The second posits that processing speed in only weakly related to the other cognitive processes and academic skills, and therefore selection of children into the three LD categories has little effect on the normal distribution of processing speed resulting in near mean performance. The present study does not provide the means for evaluating this hypothesis. Research is needed to explore whether relative strength in processing speed affects the execution of lower-level skills that are embedded within more complex tasks and therefore reduces the deleterious effects of other cognitive deficits that undermine academic competence.

With respect to academic profiles, by definition, students with LD experience academic difficulty in the area where LD occurs. According to the specificity hypothesis, however, LD students not only should manifest deficits in the area of their LD but also should demonstrate pockets of relative academic strength. This stands in contrast to generalized academic deficiencies, of comparable magnitude across academic areas, as would be expected for students with mental retardation. In fact, our academic profile analyses supported the specificity hypothesis in all four academic LDs. Although NLD students experienced flat performance across the four academic areas, reading comprehension LD students demonstrated relative strength on calculations ($p = .07$), students with word reading LD experienced relative strength on applied problems and reading comprehension, students with applied problems LD manifested relative strength on reading comprehension and word reading, and students with calculations LD showed relative strengths on reading comprehension and word reading.

Results of these profile analyses not only lend support to the LD specificity hypothesis and the validity of the LD construct but also provide insight into the extent to which reading and mathematics LD overlap. Although findings were not entirely consistent, we found two sources of tentative support for the notion that LD is more specific to reading or mathematics than overlapping. First, for reading LD, the area or areas of academic relative strength tended to occur in mathematics; for mathematics LD, the area or areas of academic relative strength tended to occur in reading. The one exception to this pattern was word reading LD, for which reading comprehension (as well as applied problems) was identified as a relative strength.

The second source of support for the notion that LD is more specific than general to reading or mathematics is found in our estimates of the overlap between these conditions. On higher order skills, 2.6% of the 684 students in this study experienced both forms of LD (reading comprehension and applied problems); but the great majority of students were designated as LD in one or the other academic area: 5.8% only on reading comprehension and 5.6% only on applied problems. A similar pattern emerged for lower-order skills, even though a different test, with a different normative framework, was employed. That is, 3.8% of the 684 students in the study were identified as having word reading as well as calculations LD, whereas most students experienced LD in word reading (6.6%) or calculations (10.1%). Consequently, results indicate that although comorbidity does occur, it is limited to approximately 20% of students with LD, adding credence to the notion that reading and mathematics LD may be distinct.

That most students do not experience the severe academic deficits associated with LD across reading and mathematics is supported by Dirks, Spyer, van Lieshout, and de Sonneville (2008), who found that when using the 25th percentile as the cut point, 7.6% of their sample was classified with comorbid reading and mathematics LD whereas 19.9% was identified as specific word reading LD and 10.3% as specific calculations LD; when using the 10th percentile, the prevalence of comorbidity was lower (1.0%), 8.0% identified as word reading LD and 5.6% as calculations LD. Our prevalence rate, which was based on a cut point of the 15th percentile, fell in the middle Dirks et al.'s estimates, as would be expected. That reading and mathematics LD may be distinct gains credence from findings that there are independent genetic sources of variation related to measures of decoding fluency and mathematics (Hart, Petrill, & Thompson, 2010). Moreover, in randomized controlled trials, students with mathematics LD alone and those with comorbid reading and mathematics LD respond comparably to number combination or word-problem remediation (e.g., Fuchs et al., 2009). Even so, some work suggests that most students with reading LD appear to have active mathematics individual educational programs (Kavale & Reese, 1992), although we could not locate more recent or national estimates.

Before closing, we note several study limitations that readers should consider when interpreting the findings. First, as already mentioned, our sample sizes for the LD groups were small. This is understandable given that LD required academic performance below the 15th percentile. Even so, the small sample sizes make it difficult to detect differences when following up the significant multivariate interactions. Second, our reading and mathematics measures involved different tests (for reading comprehension, WRMT; for word reading and calculations, WRAT; and for applied problems, WJ-III Applied Problems), each with a different normative sample. Although this did not affect the academic profile analyses, for which we relied on this study's normative sample, the use of different national norms in the various tests does affect the identification of LD, and readers should exercise caution with respect to the estimates of prevalence reported in the results section. The third limitation of the present study is that our exploration of cognitive dimensions was limited to nonverbal problem solving, processing speed, concept formation, language, and working memory. It is possible that the inclusion of other cognitive dimensions, such as phonological processing and rapid naming speed, or the use of different measures representing the cognitive dimensions we did include may result in a different pattern of results. Clearly, in light of these methodological limitations, additional research is warranted on the LD specificity hypothesis, about the nature of distinctive strengths and weaknesses of LD, and concerning whether reading and mathematics LD are distinct.

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