Psychology in the Schools, Vol. 43(8), 2006
Published online in Wiley InterScience (www.interscience.wiley.com).

DOI: 10.1002/pits.20192

COGNITIVE HYPOTHESIS TESTING AND RESPONSE TO INTERVENTION FOR CHILDREN WITH READING PROBLEMS

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Response to intervention (RTI) must be combined with comprehensive cognitive assessment to identify children with learning disabilities. This article presents the Cognitive Hypothesis Testing (CHT) model for integrating RTI and comprehensive evaluation practices in the identification of children with reading disabilities. The CHT model utilizes a scientific method approach for interpreting cognitive and neuropsychological processes together with evaluation of ecological and treatment validity data to develop targeted interventions for students who do not respond to standard academic interventions. A case study highlights how CHT practices can lead to effective interventions for a child who did not respond to a phonologically based reading intervention. In addition, discriminant analyses of 128 children with reading disabilities revealed the presence of Global, Phonemic, Fluency-Comprehension, and Orthographic subtypes. Results suggest subtypes show disparate cognitive profiles that differentially impact their reading achievement, supporting our contention that individual assessment of cognitive processing strengths and weaknesses is not only necessary for identifying children with reading disabilities but also can lead to individualized interventions designed to meet their unique learning needs.

Identification of Reading Disabilities

Difficulty with reading acquisition is the most common referral for educational assessment, with an estimated 5% of children identified as having reading disabilities (Ramus, 2001; Schrank & Flanagan, 2003) because they do not show adequate response to classroom instruction. The response to intervention (RTI) literature has primarily focused on the most common cause of reading disability, poor phonological awareness (e.g., Shaywitz & Shaywitz, 2005; Torgesen et al., 1999; Vellutino et al., 1996), while the reading literature includes a variety of explanations for reading disabilities, ranging from genetic determinants (Chapman, Raskind, Thomson, Berninger, & Wijsman, 2003; Compton, Davis, DeFries, Gayan, & Olson, 2001) to environmental factors such as inadequate instruction or number of books read outside of school (Cunningham & Stanovich, 1990; Vellutino, Fletcher, Snowling, & Scanlon, 2004). Regardless of causation, reading is a complex process that puts considerable demands on the cognitive system and requires use of a network of brain areas (e.g., Hale & Fiorello, 2004; Ramus, 2004; Semrud-Clikeman, 2005). Due to the many factors that contribute to this learning process, informed, accurate, and comprehensive evaluations are imperative for accurate identification and treatment of reading problems.

The extant literature on reading and learning disabilities identifies various correlates of reading failure. Depending on the source, factors such as phonemic awareness, language comprehension, lexical/semantic skills, verbal working memory, rapid automatic naming, and oral word fluency have been found to contribute significantly to reading acquisition and competency (Evans, Floyd, McGrew, & Leforgee, 2001; Fletcher, Shaywitz, & Shankweiler, 1994; Semrud-Clikeman, Guy, & Griffin, 2000; Stein & McAnally, 1995; Torgesen, Wagner, & Rashotte, 1994; Torgesen,

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Wagner, Rashotte, Burgess, & Hecht, 1997; Vellutino et al., 1996; Wolf & Bowers, 1999). Throughout the literature, however, different variable combinations have been used to predict reading performance, with some studies omitting potentially important predictors, which has problematic implications both for subsequent research and for practice (Evans et al., 2001).

Concern for a lack of comprehensive assessment in the identification of reading disabilities is compounded by the current movement in the school psychology field toward the RTI model (Bradley, Danielson, & Doolittle, 2005; Fuchs, Mock, Morgan, & Young, 2003). Recognizing the methodological weaknesses associated with ability–achievement discrepancy for specific learning disability (LD) identification (Fuchs et al., 2003), the RTI approach alternatively suggests children should be classified with LD if they do not respond to empirically supported interventions. The RTI model has a number of strengths, including providing preventative services to children before they experience significant academic failure, and emphasizing ongoing progress monitoring to establish what interventions work and those that do not. Early intervention can lead to successful reading outcomes in a majority of children (Torgesen, 2002), and full implementation of an RTI model has the potential to decrease the percentage of children identified as needing special education (Burns, Appleton, & Stehouwer, 2005).

Despite the well-established research base for instruction in multiple areas of reading, including phonemic awareness, phonics, fluency, and comprehension (National Reading Panel, 2000), RTI interventions typically focus on one or a few areas of difficulty (e.g., phonemic awareness) to the exclusion of many others such as higher level comprehension skills. There are numerous reasons for reading disability, and focusing on a single determinant cannot effectively identify or serve all children with the disorder. In addition, many children are referred for multiple areas of learning and/or socio-emotional difficulty, and judging RTI for children with comorbid disorders can be problematic as a result. While some RTI proponents have claimed reading disabilities are largely due to a deficit in the language system, specifically phonological processing (Shaywitz & Shaywitz, 2005), others have questioned this simple causal relationship (Eden, Wood, & Stein, 2003; Vliet, Miozzo, & Stern, 2004), and some children with hyperlexia and reading comprehension deficits actually show excellent phonological skills (Turkeltaub et al., 2004). An RTI model that does not embrace comprehensive cognitive assessment of individual differences overlooks the vast literature in cognition, cognitive assessment, neuropsychology, and learning disabilities that links cognitive processing with achievement and LD (e.g., Berninger, 2002; Hale, Naglieri, Kaufman, & Kavale, 2004; Hale & Fiorello, 2004; Mather & Gregg, 2006; Semrud-Clikeman, 2005).

Our Cognitive Hypothesis Testing (CHT; Hale & Fiorello, 2004) model for LD identification and intervention is based on four premises: (a) A number of complex cognitive and neuropsychological processes have been empirically linked to academic achievement; (b) children often have unique learning profiles of cognitive strengths and weaknesses; (c) the learning profiles must be evaluated both through direct assessment of cognitive processes and examination of ecological and treatment validity; and (d) the children's academic deficits must be remediated and/or compensated for based on underlying cognitive strengths and weaknesses. The CHT model requires RTI principles in practice, as we argue practitioners must *intervene to assess*, that all children should be served through a consultation-based problem-solving process first so that when a child does not respond to empirically supported interventions, a comprehensive CHT evaluation can be undertaken. Therefore, the CHT model can be used within the context of a larger problem-solving model that incorporates RTI methods and comprehensive assessment of cognitive processes.

In the CHT model, the presenting problem, history, and prior intervention data are examined to develop an initial theory about the child's problem. When it is hypothesized that a cognitive problem is contributing to a child's difficulty, a standardized cognitive/intellectual test is administered as a screening tool. The results are interpreted at both the nomothetic and idiographic levels, including completing a *demands analysis* of individual tasks to determine cognitive-processing requirements. Hypotheses are developed about the student's cognitive strengths and weaknesses and then evaluated through administration of related construct tests and gathering of environmental data to confirm or refute the hypotheses. This data also can be used to establish a *concordance* between the cognitive weaknesses and reading deficit(s), and a *discordance* between cognitive strengths and cognitive weaknesses/reading deficit(s) (Hale & Fiorello, 2004) to ensure the child meets the Individuals With Disabilities Education Improvement Act of 2004 (IDEA; 2004) definition of specific LD. Based on this more complete case conceptualization, problem-solving consultation is continued to develop, implement, and monitor a new intervention designed to meet the child's learning needs. In this way, the results of cognitive and neuropsychological assessments, together with record review/history, systematic observations, behavior ratings, and parent/teacher interviews, are used to develop individualized interventions based on cognitive processing strengths and weaknesses within the context of the child's natural environment to ensure ecological and treatment validity.

Cognitive Processing and Reading Disabilities

Two major approaches to the identification of cognitive processes in reading have substantial empirical support: the Cattell-Horn-Carroll theory of cognitive abilities (CHC theory) and a Lurian (see Goldberg, 2001; Hale & Fiorello, 2004; Luria, 1973) neuropsychological approach, two approaches that are not only compatible but in fact share many commonalities. Strong evidence of links between CHC cognitive processes and reading achievement have been made in the school psychology literature (Flanagan, 2000; Garcia & Stafford, 2000; Hale, Fiorello, Kavanagh, Hoeppner, & Gaither, 2001; McGrew, 1993; McGrew, Flanagan, Keith, & Vanderwood, 1997). The organization of CHC theory is hierarchal; overall cognitive functioning (*g*; stratum III) is subdivided into specific broad (stratum II) and narrow abilities (stratum I) (McGrew et al., 1997). Specific broad and narrow abilities can be identified as linked to reading achievement across the population (Fiorello & Primerano, 2005). CHC processes fundamental to basic reading include auditory processing (Ga; specifically, phonetic coding analysis and synthesis), crystallized abilities (Gc), short-term memory (Gsm; specifically, auditory memory span and working memory), long-term storage and retrieval (Glr; specifically, naming facility or rapid automatic naming and associative memory), and processing speed (Gs) (Evans et al., 2001; Hale et al., 2001; Konold, Juel, & McKinnon, 1999; McGrew & Woodcock, 2001; Schrank & Flanagan, 2003). CHC theory's empirically sound foundation and moderate to strong relations to reading achievement establish it as a strong initial framework for identifying the cognitive strengths and weaknesses of struggling readers; however, considering the underlying neuropsychological processes of these constructs provides a more detailed picture of the student's processing profile, allowing for identification of the deficit in the basic cognitive processes necessary to truly identify a learning disability.

The neuropsychological approach to reading begins with knowledge of morphological differences in the brain structure of dyslexics (e.g., Casanova, Araque, Giedd, & Rumsey, 2004; Leonard et al., 2002) and the cognitive processes that underlie reading performance rather than focusing on visible input or output demands (Hale & Fiorello, 2004). While this approach has the advantage in identifying cognitive deficits, note that all brain areas are likely to be involved in any given task, with differing degrees of involvement depending on the processing demands required (Goldberg, 2001). In addition, a child may use a variety of cognitive processes to complete any given task (Hale & Fiorello, 2004). For instance, one child with a phonological reading disability may use deficient or ineffectual cognitive processes to attempt word decoding (e.g., attempts to sound out words) while another child may depend on strengths to compensate for weaknesses (e.g., guesses at words based on configuration). As this approach clearly requires idiographic interpretation of data, extreme caution is necessary because the same score (i.e., product) does not mean the same thing (i.e., process) for all children (Hale & Fiorello, 2004). A close analysis of both the *patterns* of a student's performance and the *process* used by the student to arrive at a particular answer on a test battery is necessary for insightful interpretation (Milberg, Hebben, & Kaplan, 1986).

Early learning of any novel task, including reading, is primarily accomplished by the right hemisphere, with processing demands shifting to the left hemisphere as the task becomes familiar and then automatized (Hale & Fiorello, 2004). Struggling readers may continue to rely on right-hemisphere global/holistic processes and/or fluid problem-solving skills rather than automatizing word recognition to the left hemisphere as do skilled readers (e.g., Hale & Fiorello, 2004; Semrud-Clikeman, 2005). Skilled reading requires lower level processing of visual input, matching symbolic representations (e.g., graphemes) to auditory and semantic word memories, and higher level processing of meaning or comprehension. Breakdowns in the reading process can occur at the basic level of auditory and visual processing, the associations between the two, the retrieval of word meanings or access of prior knowledge, the working memory demands of maintaining and manipulating lexical/semantic information for comprehension, the comprehension of the literal or text explicit language, or the drawing of inferences from what is read (Adams, 1990; Berninger, 1995; Hale & Fiorello, 2004; Ruff, Marie, Celsis, Cardebat, & Demonet, 2003).

Auditory/Phonological Processing

Auditory processing (Ga), of which phonological processing is a component, is a key factor in reading achievement. Deficits in phonological processing lead to difficulty with speech perception, phonological analysis, and sound–symbol awareness (Fitch & Tallal, 2003; Fletcher et al., 1994; Hale & Fiorello, 2004; Shaywitz & Shaywitz, 2005). In CHC theory, Ga is associated with phonemic awareness/letter sound correspondence and shows moderate correlations with basic reading skills and reading comprehension, especially before age 9 years (Evans et al., 2001; McGrew & Woodcock, 2001). While phonological interventions are helpful in remediating a large proportion of children with early reading difficulties (Torgesen, 2000), approximately 5% do not respond to these interventions. Children with phonological dyslexia show atypical functional MRI or positron emission tomography activation in response to phonological tasks in the left temporal and parietal regions (e.g., Pugh et al., 2000; Ruff et al., 2003; Shaywitz et al., 2003; Shaywitz & Shaywitz, 2005). This pattern reflects impairment in the left-hemisphere multimodal temporal-parietal convergence zone (e.g., angular gyrus) that connects visual and auditory language processes (Hale & Fiorello, 2004). Some of these children use an intact occipital-temporal ventral stream as an alternate route to use visual cues (e.g., letters) to guess at words based on configuration (e.g., visual memory), bypassing the dysfunctional dorsal stream, using visual cues and word memory to identify words (Shaywitz et al., 2003). As these findings suggest that the left posterior brain structures are functionally different in children with phonological reading disability, determining whether the deficit is caused by an auditory (i.e., phoneme), a visual (i.e., grapheme), or an integration (i.e., phoneme–grapheme correspondence) problem is an important distinction to make in an evaluation (Hale & Fiorello, 2004).

Visual/Orthographic Processing

Visual processing (Gv), as it is assessed on most intelligence tests (generally visual discrimination, recognition, or memory of pictures or designs), has not been shown to be significantly related to reading achievement in typical populations; however, we know that reading is a visual task. Both visual and auditory temporal processing predict preschooler reading development (Hood & Conlon, 2004), and graphemic (individual printed letters) and orthographic (visual word patterns) skills are related to reading speed independent of phonological skills (e.g., Berninger, 1995; Barker, Torgesen, & Wagner, 1992; Hale & Fiorello, 2004). Visual processes are predictive of word reading in children with reading disability, suggesting that they continue an immature reliance on graphemic or orthographic skills to compensate for phonological deficits (e.g., Hale et al., 2001; Shaywitz et al., 2003), yet these processes are less relevant for skilled readers. Neuroimaging studies have shown that visual processing in the left ventral stream is important in orthography (Flowers et al., 2004) whereas morpheme recognition and fluency are related to the auditory-language areas, the posterior temporal-parietal areas, and Broca's area (Joseph, Nobel, & Eden, 2001). Stein (2001) noted that some children with orthographic reading disability demonstrate impaired magnocellular functioning, directly affecting the dorsal visual pathway from the occipital to the parietal lobe. Children with this type of reading disability show reduced brain activity in the primary visual cortex and extrastriate areas (Demb, Boynton, & Heeger, 1998) and fail to activate visual areas typically recruited (Eden, VanMeter, Rumsey, Maisog, Woods, & Zeffiro, 1996). Most subtypes of reading disability have related motion-processing deficits (Ridder, Borsting, & Banton, 2001), which could explain why some children complain that letters and words move when reading, and display many omission and substitution errors.

Sensory Memory and Working Memory

Different types of memory are required to read competently, including auditory (short-term) memory and working memory, sometimes referred to in cognitive psychology as the phonological loop (memory span) and central executive (Gathercole & Baddeley, 1993). Both sensory memory and working memory are considered part of Gsm in CHC theory and show moderate relationships with basic reading skills and reading comprehension (Evans et al., 2001; Hale et al., 2001; McGrew & Woodcock, 2001). The cognitive psychology research literature is replete with studies that demonstrate the importance of working memory and its relationship to reading and academic achievement (Fuchs, Compton, & Fuchs, 2005; Pickering & Gathercole, 2005). Mediated by the prefrontal cortex, working memory plays an instrumental role in enabling a child to decode words; children must hold a template of letters in working memory until a word is sounded out and deciphered (Semrud-Clikeman et al., 2000). In addition, working memory is linked to temporal processing and prefrontal systems that allow the child to learn to access previously learned information (Semrud-Clikeman, 2005), suggesting working memory demands are significant for both word reading (e.g., decoding unfamiliar words) and comprehending written text (e.g., maintaining and comparing written content to prior knowledge). In addition, children with executive deficits tend to guess at words rather than decode them due to disinhibition (van der Schoot, Licht, Horsley, & Sergeant, 2002). Not surprisingly, children with reading disabilities have executive deficits that affect their monitoring, adjusting, and regulating cognitions during reading (Wong, 1992), which lead to comprehension deficits independent of phonological/articulatory functions subserving word recognition (Swanson & Ashebaker, 2000).

Long-Term Memory Storage and Retrieval and Crystallized Abilities

Related to working memory, long-term memory storage and retrieval (Glr) and crystallized abilities (Gc) also are critical for reading competency, including such CHC processes as associative memory, meaningful memory, and ideational fluency. CHC Glr measures are moderately correlated with both basic reading skills and reading comprehension (Evans et al., 2001; McGrew & Woodcock, 2001). Ideational fluency, together with Gs, is related to Rapid Automatized Naming (RAN), often identified as the second part (together with auditory or phonological processing) of the "double deficit" type of reading disability (Wolf & Bowers, 1999). Related to lexical/semantic knowledge and language development, and directly impacted by Glr, Gc is a strong predictor of basic reading and comprehension skills (Evans et al., 2001; Hale et al., 2001; McGrew & Woodcock, 2001). While lower level processes such as decoding, word recognition, and explicit comprehension are likely the province of the left posterior regions, higher level implicit or inductive comprehension skills require fluid reasoning (Gf) and right-hemisphere functions (e.g., Bryan & Hale, 2001; Hale & Fiorello, 2004; Rourke, 1994). Children with right-hemisphere dysfunction are unlikely to show reading comprehension problems in the early grades, when the meaning in text is explicit and concrete, but they struggle with higher level or implicit comprehension (Bryan & Hale, 2001; Rourke, 1994; Williams et al., 2002). Although Gc is most likely related to temporal lobe functions, the frontal executive-working memory system is responsible for Glr, with encoding being a left frontal task (in combination with the hippocampus) and retrieval a right frontal one (Tulving, Kapur, Craik, Moscovitch, & Houle, 1994). Determining whether a long-term memory based reading comprehension deficit is due to encoding, storage, or retrieval problems would be helpful for designing targeted interventions.

Processing Speed/Rapid Automatic Naming

Processing speed relates to the rate of processing or automaticity with simple cognitive tasks. Gs is associated with RAN, basic reading skills, and comprehension, with theoretical foundations including both perceptual and semantic processing speed (Schrank & Flanagan, 2003). When considering Gs from a neuropsychological perspective, it is important to consider automaticity of word recognition, retrieval difficulties, expressive speech and language characteristics, and slow psychomotor pace during testing (Hale & Fiorello, 2004). Children with reading disabilities have difficulty with selective and sustained attention, inhibition, set maintenance, flexibility, and phonemic production (Kelly, Best, & Kirk, 1989), suggesting that dysfunctional frontal-basal ganglia-thalamus–cerebellar circuits could account for difficulties in processing speed, working memory, sequencing, temporal relationships, and performance monitoring in some children with reading disabilities. The thalamus is in part responsible for regulation of both visual and auditory processes (Hale & Fiorello, 2004), the cingulate is responsible for online monitoring of performance (Lichter & Cummings, 2001), and the cerebellum serves as the brain's main internal timepiece (Ivry, Justus, & Middleton, 2001), with 80% of children with reading disabilities showing some form of cerebellar impairment (Nicholson & Fawcett, 2001). In fact, about 70% of children with reading disability and rapid automatic naming deficits can be identified on the basis of MRI measurements of the cerebellum and pars triangularis (Eckert et al., 2003).

Reading Disability Subtypes

If different cognitive/neuropsychological processes are necessary for reading competency, clumping disparate subtypes of reading disabilities together may obscure important differences in their processing profiles and their intervention outcomes. To examine this issue, we used a hierarchical cluster analysis of the WIAT-II Word Reading, Pseudoword Decoding, and Reading Comprehension subtests for children with reading disabilities ($n = 128$; Wechsler, 2003) to determine if subtype cognitive profiles were related to different reading outcomes. The results of the Average Linkage Within Groups variant of the Unweighted Pair-Group Method Arithmetic Average, which minimizes within-group variability, revealed four reading disability subtypes (see Figure 1) according to the agglomeration schedule coefficient changes from Step 4 (386.87) to Step 3 (562.97). We then used forced-entry discriminant analysis and Tukey's Honestly Significant Difference post hoc comparisons of the WISC-IV Full Scale IQ (FSIQ; Wechsler, 2003), four factor Indices, and individual subtests to determine the best method for identifying reading disability subtypes and how these subtypes differed from typical children ($n = 791$).

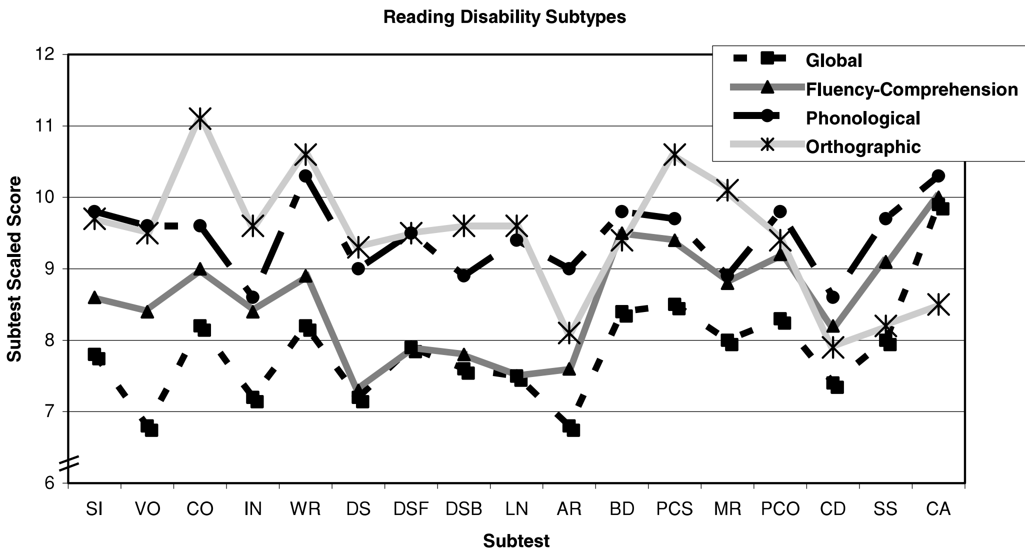

FIGURE 1. Subtest profiles for the four reading disability subtypes. SI = Similarities; VO = Vocabulary; CO = Comprehension; IN = Information; WR = Word Reasoning; DS = Digit Span; DSF = DS Forward; DSB = DS Backward; LN = Letter–Number Sequencing; AR = Arithmetic; BD = Block Design; PCS = Picture Concepts; MR = Matrix Reasoning; PCO = Picture Completion; CD = Coding; SS = Symbol Search; CA = Cancellation.

Examining the reading and intellectual scores reported in Table 1 and Figure 1, and the relationships among variables, these groups were identified as *Global*, *Phonemic*, *Fluency-Comprehension*, and *Orthographic* reading disability subtypes, which have been identified in similar subtype studies (e.g., Morris et al., 1998). For Word Reading and Pseudoword Decoding, children with the Global Subtype scored lower than did the Phonemic or Fluency-Comprehension subtypes, but these groups still were below the Orthographic and Typical groups. For Reading Comprehension, both the Global and Fluency-Comprehension subtypes scored poorly compared to the other groups. The Global subtype also was lower than were other groups on the intellectual measures, suggesting that lower overall functioning increases the likelihood of significant reading impairments, at least when this level of global score or nomothetic analysis is used. Given that reading disability subtypes display disparate profiles that extend beyond language processes that predict group membership (Waber, Forbes, Wolff, & Weiler, 2004), it makes sense to look beyond nomothetic data when identifying and serving these children.

In an attempt to determine how best to identify reading disability subtypes, three separate discriminant analyses using the FSIQ, the four factor Indices, or the individual subtests were undertaken. As can be seen in Table 1, the FSIQ showed some discriminant validity, accounting for a highly significant amount (26%) of between-groups variability, but classification rates were poor (50.4%), with all children either classified as Global or Phonemic subtypes. At the Index level, all four factor scores discriminated between subtypes, accounting for 36% of the between-group variance, and classification rates were still poor (54.7%). However, when the highly idiographic subtest approach was used as the level of analysis (see Table 2), identification rates improved dramatically (68.6% correctly classified), with over 59% of between-subtype variance accounted for by the intellectual subtests. Except for the Digit Span Forward and Coding subtests, which were uniformly impaired relative to the typical group, the intellectual subtests discriminated between subtypes, accounting for substantial portions of between-subtype variance (9% for Block Design;

Table 1
Nomothetic Results for WISC-IV/WIAT-II Standardization and Reading Disability Subtypes

		Typical ($n = 791$)	Global ($n = 49$)	Phonemic ($n = 34$)	Fluent/Comprehension ($n = 29$)	Orthographic ($n = 16$)	F^1
WR	*M*	99.94	68.39[a,b,c,d]	82.56[a,d]	84.34[a,d]	96.69	74.67
	SD	14.84	7.57	6.93	5.19	6.70	
PW	*M*	100.47	73.12[a,b,c,d]	84.68[a,d]	85.79[a,d]	104.00	61.86
	SD	14.42	5.14	7.71	8.39	6.29	
RC	*M*	100.10	68.84[a,b,d]	100.88	77.10[a,b,d]	96.31	65.13
	SD	15.67	9.72	9.27	7.54	6.11	
FSIQ	*M*	100.33	82.77[a,b,d]	95.45	90.33[a]	96.46	20.50
	SD	14.25	8.21	9.70	8.90	14.38	
VC	*M*	99.59	86.17[a,b,d]	97.58	92.18	99.93	12.57
	SD	13.93	9.41	8.54	10.94	10.24	
WM	*M*	99.53	84.36[a,b,d]	94.74	85.04[a,b,d]	95.40	19.94
	SD	14.40	9.20	11.01	13.75	15.78	
PR	*M*	100.38	89.71[a,d]	96.85	95.34	100.31	7.59
	SD	14.49	11.34	10.87	12.51	12.56	
PS	*M*	99.94	87.24[a]	95.14	92.21	89.50[a]	14.33
	SD	13.70	13.08	13.74	9.63	15.17	

Note. [1]All F ratios significant at $p < .01$.
[a]Less than typical group.
[b]Less than Phonemic subtype.
[c]Less than Fluency-Comprehension subtype.
[d]Less than Orthographic subtype.
FSIQ = Full Scale Intelligence Quotient; VC = Verbal Comprehension; PR = Perceptual Reasoning; WM = Working Memory; PS = Processing Speed; WR = Word Reading; PW = Pseudoword Decoding; RC = Reading Comprehension.

Table 2
Significance Tests and Wilks's Λ Results for WISC-IV Discriminating Variables

Variable	F	p	Wilks' Λ
Similarities	4.41	.006	.884
Vocabulary	12.73	<.001	.726
Comprehension	7.73	<.001	.813
Information	4.56	.005	.881
Word Reasoning	6.02	.001	.848
Digit Span Forward	1.79	.154	.950
Digit Span Backward	5.19	.002	.867
Letter-Number Sequencing	5.27	.002	.865
Arithmetic	6.56	<.001	.837
Block Design	3.29	.024	.911
Picture Concepts	3.43	.020	.907
Matrix Reasoning	5.25	.002	.865
Picture Completion	3.46	.019	.907
Coding	1.80	.152	.949
Symbol Search	3.43	.020	.908
Cancellation	.96	.416	.972

27% for Vocabulary). Note that the Vocabulary subtest accounted for more between-subtype variance than even the FSIQ, which suggests that collapsing disparate subtest scores into global Index or FSIQ scores obscures meaningful individual differences (Fiorello et al., in press).

For typical children, significant ($p < .01$) correlations between subtests and reading domains were all positive. For Word Reading, the strongest correlations were for the Verbal subtests (range = .55 for Similarities to .62 for Vocabulary and Information), with moderate correlations found for the Digit Span ($r = .48$) and Letter–Number Sequencing ($r = .48$) subtests. The Pseudoword Decoding subtest correlations were generally lower but in a similar pattern, with the exception of the Digit Span ($r = .46$) and Letter–Number Sequencing ($r = .44$) relationships, which were comparable to those found for Word Reading. For Reading Comprehension, fairly strong relationships were again found for the Verbal subtests (range = .52 for Comprehension to .66 for Vocabulary), with other relationships typical of those found for Word Reading. It would appear that prior learning or crystallized knowledge, language competence, and auditory–verbal working memory are all related to the reading skills of typical children, suggesting there is primarily a left-hemisphere dominance for adequate reading in this population. For many of these children, reading appears to be natural and automatic, as they easily coordinate their mental processes to achieve reading competence.

For the Global subtype ($n = 49$), reading and intellectual deficits were found, with Verbal Comprehension, Working Memory, and Processing Speed measures quite low. The classification analysis found that 78% of these children were classified correctly on the basis of these measures. For the Verbal Comprehension subtests, the profile suggests that these children had the most difficulty on the Vocabulary and Information subtests, suggesting auditory–verbal–crystallized and/or language deficits–a pattern found for many children with LD (Hale et al., 2001). They also had considerable difficulty on the Working Memory measures and the Coding subtest. Post hoc analyses revealed this group to be lower functioning than are typical children on all subtests except Block Design and Picture Completion, suggesting multiple cognitive impairments with a few spared nonverbal functions. Interestingly, there were low or negative correlations between WISC-IV Working Memory subtests and the WIAT-II Word Reading and Pseudoword Decoding (range = $-.17$ to .14, $p < .05$) subtests. This suggests that these children do not utilize the same auditory–working memory and phoneme–grapheme correspondence skills typical children use when decoding words (typical group range = .44 to .48, $p < .01$). Reading comprehension is likely impaired by crystallized, receptive and expressive language, and working memory/executive impairments. Perhaps this Global reading disability group uses visual long-term memory, perceptual analysis and synthesis, and problem-solving skills in an attempt to compensate for auditory–linguistic–crystallized–working memory processing-speed deficits, which would be consistent with those who compensate for their reading disability using right-hemisphere functions (Hale et al., 2001; Shaywitz et al., 2003). Although several left-hemisphere and frontal networks are likely impaired in this subtype, this pattern is remarkably similar to the one displayed by children who experience brain stem timing deficits that secondarily affect language processing and reading (Banai, Nicol, Zecker, & Kraus, 2005).

The Phonological subtype ($n = 34$) was expected given the vast literature supporting the link between phonological awareness and reading competency (Shaywitz & Shaywitz, 2005). This subtype was classified with 77% accuracy, showed relative weaknesses on the Information, Digit Span (especially Digits Backward), Arithmetic, Matrix Reasoning, and Coding subtests, similar to the Arithmetic, Coding, Information, Digit Span profile that has been found in children with LD (Prifitera & Dersh, 1993; Vargo, Grosser, & Spafford, 1995). Although this profile is not uncommon and its utility in differential diagnosis has been challenged (Watkins, Kush, & Glutting, 1997), this may be because previous research using it has examined heterogeneous LD groups.

This pattern of performance appears to have its greatest impact on single word reading, as this group's Reading Comprehension score was not discrepant from that of typical children, as was the case for Word Reading and Pseudoword Decoding. Interestingly, the Verbal Comprehension subtests showed modest relationships with Word Reading scores (range = .26 to .39, $p < .05$), but these skills were virtually absent in the prediction of their reading of nonsense words on Pseudoword Decoding. For real words, this subtype could first attempt a phoneme (temporal lobe)–grapheme (occipital lobe) approach using their dorsal stream to read words, but if this fails, they might guess at words based on initial letter or general word configuration, trying to access a known visual representation of the word using the lexical–semantic route or ventral stream (occipital–temporal) functions (Hale & Fiorello, 2004). However, for nonsense words, they no longer can directly access known words from lexical–semantic memory or guess at words based on configuration, and instead have an increased working memory load. Assessment of dorsal and ventral route functions can be critical not only for identification of reading disability but also for developing specific interventions (Shaywitz & Shaywitz, 2005).

The primary difference between the cognitive profile of the Global subtype reported earlier and the Fluency-Comprehension subtype ($n = 29$) is the latter had higher Verbal Comprehension and Perceptual Reasoning skills, which were not different from those of the typical group. Given this finding, it would seem surprising that the relatively better Verbal Comprehension performance experienced by this group did not translate into better Reading Comprehension scores, as this was this group's weakest area when compared to the performance of typical children. This subtype performed just as poorly as the Global subtype on auditory–working memory and processing-speed tasks, suggesting that executive problems lead to comprehension deficits (e.g., Semrud-Clikeman, 2005). This could explain why this subtype was classified with only 50% accuracy, with 26% misclassified as the Global subtype. However, their adequate Perceptual Reasoning performance suggests that this subtype could have auditory–verbal working memory deficits with attempts to compensate using novel problem-solving or fluid abilities, nonverbal concept formation, and convergent processing skills. Note that the WISC-IV subtests and the Word Reading/Pseudoword Decoding subtests were not related for this subtype, suggesting possible phonemic or sequential processing deficits that lead to poor word attack skills. This subtype did appear to have difficulty with the Coding subtest, suggesting symbolic representation, symbol association learning, or processing speed was this subtype's weakest area of nonverbal performance. Results suggest that this could be the reading disability subtype that laboriously sounds out words or retrieves words from long-term memory, which in turn taxes working memory, with the result being very slow reading or poor reading fluency, known to lead to comprehension deficits (e.g., Wolf & Bowers, 1999).

Finally, the Orthographic subtype ($n = 16$) results are difficult to interpret because of the extremely small sample size and their poor classification based on WISC-IV measures (55% correctly classified). These children appeared to do well on the WISC-IV and WIAT-II subtests, with mean scores for both suggesting no significant achievement weakness. Certainly, one possibility is that this small group does not have a reading disability—this subtype's reading underachievement could be due to other issues; however, idiographic examination of the subtype profile does suggest difficulty with the Arithmetic and Processing Speed subtests relative to that of typical children, subtests that were often significantly low in the other reading disability subtypes. Although orthographic problems have been known to cause impaired reading fluency and comprehension (e.g., Berninger, 1995, Wolf & Bowers, 1999; Stein, 2001), this was not apparent for this subtype, whose WIAT-II Reading Comprehension score was in the average range.

Although these results should be considered preliminary given the small sample size and should be replicated across other intellectual/cognitive measures, these findings suggest that the subtest level of analysis is relevant for children with reading disability. Despite the problems associated with subtest level of analysis (e.g., McDermott, Fantuzzo, & Glutting, 1990) and that profile variability is not necessarily reflective of a specific LD (e.g., Watkins & Glutting, 2000), it is important to recognize that the FSIQ or factor level of interpretation does little to inform intervention should these children fail to respond to intervention. Instead of basing conclusions on subtests alone, Hale and Fiorello's (2004) CHT model suggests that the intellectual measure should be used as a *screening* test for processing strengths and weaknesses, and hypotheses about subtest performance should be verified or refuted using additional measures and data sources. This will not only allow for determination of whether a child has the prerequisite deficit in the basic psychological processes required for the LD definition (Hale et al., 2004; Kavale, Holdnack, & Mostert, 2005) but also helps practitioners develop targeted interventions after a child does not respond to typical interventions. The following case study illustrates the CHT assessment-intervention model for a child with a reading disability.

Case Study

Initial Evaluation and RTI

Jerry is an 8-year 7-month-old boy described as active and engaging, with frequent off-task and disruptive behaviors that occasionally led to verbal conflicts with the teacher and/or peers. His teacher referred him to the Intervention Assistance Team (IAT) for behavioral and word reading concerns, but she noted that he had fairly good reading comprehension. Although the teacher reported concerns about Jerry's attention, impulse control, activity level, and oppositional behavior, the team felt that these behaviors were due primarily to difficulty following directions, understanding language, and completing work.

The team intervention included changing his seat to the front of the classroom, daily readings in the home, and a daily home–school report card indicating whether Jerry's in-class reading that day had been excellent, good, average, or below average. During a period of 3 weeks, results indicated that Jerry was average or better for 3 of the 15 days. Although the parent was to return the card each day, this happened for only 9 of the 15 days, reportedly because Jerry "refused" to read.

Given his word reading problems, the IAT decided to provide Jerry with systematic phonics instruction using the Orton-Gillingham multisensory approach. Although this intervention clearly addresses the core deficit in most word reading disorders (Stanovich & Siegel, 1994), Jerry's attention, language, and reading problems were still apparent after 6 weeks. In addition, the intervention did little to address classroom behavior, and he was suspended briefly following a fight with a peer. The IAT met again to discuss Jerry's progress and decided to refer him for a comprehensive evaluation to develop targeted intervention strategies.

Comprehensive Team Evaluation for LD

The school psychologist found a discrepancy between Jerry's intellectual performance on the Differential Ability Scales (DAS; Elliott, 1990; see Table 3) and the Woodcock-Johnson Tests of Achievement-Third Edition (WJ-III ACH; Woodcock, McGrew, & Mather, 2001a) Letter/Word Identification (SS = 78), Reading Fluency (SS = 82), and Passage Comprehension (SS = 87) tests, which led the team to classify Jerry as a child with a specific learning disability in reading. As can be seen in Table 2, there was significant DAS subtest scatter, with results suggesting some difficulty in the Verbal and Nonverbal domains, and on the Recall of Digits and Speed of Information Processing diagnostic subtests. The speech and language evaluation revealed significant word finding, language formulation, and syntactic problems, but few receptive language concerns. Despite clinical range scores on the Achenbach Teacher Report Form (TRF; Achenbach, 1991) for attention,

Table 3
Differential Ability Scales Results for Jerry

Verbal *SS* = 98	Nonverbal Reasoning *SS* = 101	Spatial Ability *SS* = 101
Word Definitions *T* = 42	Matrices *T* = 60	Recall of Designs *T* = 47
Similarities *T* = 56	Sequential and Quantitative Reasoning *T* = 42	Pattern Construction *T* = 55
Diagnostic Subtests		
Recall of Digits *T* = 36		
Recall of Objects *T* = 48		
Speed of Information Processing *T* = 43		

social, and oppositional behaviors, the team felt language issues were affecting Jerry's reading and behavior, and recommended language and resource services.

Cognitive Hypothesis Testing Evaluation

The special education teacher desired additional information about Jerry's learning characteristics following the evaluation, and referred him for a CHT (Hale & Fiorello, 2004) evaluation through our Student Neuropsychological Assessment Profiles for Innovative Teaching (SNAP-FIT) project.

The recently administered DAS data were used to develop initial hypotheses about Jerry's cognitive strengths and weaknesses. Results showed relative difficulty in several areas but few consistencies, rendering the General Cognitive Ability (GCA) score virtually meaningless (e.g., Fiorello et al., in press; Fiorello, Hale, McGrath, Ryan, & Quinn, 2001). Although the Similarities score was strong, his Vocabulary appeared to be less well developed. Although the DAS does not require as much expressive language as some other measures (Hale & Fiorello, 2004), this finding could be due in part to language formulation or word retrieval issues. Although Jerry's Matrices performance was strong, his Sequential and Quantitative Reasoning score was comparatively low, which could be related to the sequential processing demands. Nothing in his Spatial Ability performance suggested any problem with graphomotor skills, but his Speed of Information Processing was somewhat low, and his handwriting was qualitatively poor. His lower Recall of Digits would be consistent with an auditory processing or phonological deficit, but his item performance suggested sequencing problems (i.e., saying "632" for *623*), not encoding or recalling specific digits.

Based on the history and the DAS results, three hypotheses were identified. The first hypothesis was that Jerry had a language disability affecting reading, writing, and oral language, affecting expressive more than receptive language. Given that the comorbidity of language deficits (i.e., aphasia) and motor deficits (i.e., apraxia) is fairly common, this could account for the relative difficulty with graphomotor skills; however, since the most common cause of word reading disability is auditory or phonological in nature (e.g., Stanovich & Siegel, 1994), and most cognitive measures fail to directly assess auditory processing skills, receptive and expressive language and phonological awareness were examined. Children with Attention-Deficit/Hyperactivity Disorder (ADHD) also are likely to have executive dysfunction and language formulation/word retrieval problems, so a third hypothesis explored the executive functions and their relationship to apparent fluid reasoning, sequential processing, and psychomotor speed issues.

The CHT results (see Table 4) showed adequate receptive language and comprehension, but inconsistent performance on the Woodcock-Johnson III Tests of Cognitive Abilities (WJ-III; Woodcock, McGrew, & Mather, 2001b) Ga tests. While he had no difficulty with auditory attention,

Table 4
Cognitive Hypothesis Testing Results for Jerry

Language/Phonological	*SS*	Executive/Working Memory	*SS*
CELF-4 Receptive		NEPSY	
Concepts and Directions	95	Tower	85
Word Classes Receptive	100	Halstead-Reitan Trails B	
Understanding Spoken Paragraphs	110	Time	79
CELF-4 Expressive		Errors	56
Word Structure	85	Hale Cancellation Task	
Formulated Sentences	90	Time	85
Word Classes Expressive	95	Correct	69
Boston Naming Test		Go/No Go Test	
Free Recall+Semantic	77	Raw Score/Total Possible	24/30
Cued Recall	96	Conners' CPT-II	
Controlled Oral Word Association Test		Omissions	78
Letters	89	Commissions	85
Category	101	Reaction Time	92
Woodcock Johnson III		Block Change	81
Sound Blending	84	Interstimulus Interval Change	78
Incomplete Words	95	Woodcock Johnson III	
		Auditory-Working Memory	85

Note. All normative scores transformed to Standard Scores (*SS*; *M* = 100, *SD* = 15; higher scores = better performance). CELF-4 = Clinical Evaluation of Language Fundamentals–4th Edition; CPT-II = Conners' Continuous Performance Test–2nd Edition.

phonemic processing, and auditory closure on the Incomplete Words test, his Sound Blending test score was low. Taken together, we might conclude that his Ga score was just low, suggesting problems with Ga, which would be consistent with a phonologically based reading disability. But in reality, these subtests show the difference between Jerry's auditory processing/closure and phonemic analysis and assembly skills, with the latter being the specific weakness related to sequencing problems seen throughout his profile. This would be consistent with his adequate Phonological Awareness CELF-4 score. Expressively, Jerry's Boston Naming Test performance was poor for free recall, but retrieval improved with cuing. Jerry's Controlled Oral Word Association Test (COWAT) performance suggested difficulty recalling words when the stimulus was letters, but he had no difficulty recalling words belonging to a semantic category. These language findings can be related to executive-mediated word retrieval and language formulation deficits, consistent with the Hemispheric Encoding Retrieval Asymmetry (see Tulving et al., 1994), and these deficits also would be consistent with the CELF-4 word structure and syntactic problems. Finally, Jerry's attention, working memory, and executive functions appear to be impaired. He had difficulty with planning, organization, monitoring, evaluating, and shifting/flexibility, all characteristics of children with ADHD (see Hale, Fiorello, & Brown, 2005), which not only explains his classroom behavior but also his cognitive profile, language problems, and reading deficits as well.

After receiving the CHT feedback, the targeted intervention phase began with the parents deciding to take Jerry to the pediatrician for a trial of stimulant medication, which normalizes the "brain boss" or hypoactive executive circuits in ADHD (see Hale et al., 2005). Although beyond the scope of this article, our double-blind placebo controlled trial of stimulant medication (see Hale et al., 2005; Hale et al., 1998; Hoeppner et al., 1997) revealed significant low-dose cognitive and high-dose behavioral responses, so the lower dose was chosen, with behavioral strategies offered to address disruptive behavior. For the targeted academic intervention, we brainstormed interventions to help Jerry combine phonemes and morphemes quickly and efficiently. First, Jerry read three passages from his reader, and recorded all errors. Using these words, the teacher then had Jerry break down these words using slashes (e.g., for the word *cluster*, Jerry would write "cl/us/ter"). Then using different flash cards of the common letter clusters, the teacher had Jerry say the letters, then the sounds they made. Then the teacher started showing Jerry two or more cards in rapid succession, asking him to combine them. For instance, Jerry would see the card "cl" then "ust," and he would say "clust." After this was accomplished, additional morphemes were introduced (e.g., "cl" + "us" + "ter" would read "cluster"), thereby helping Jerry to rapidly combine phonemes and morphemes to form common words.

Because of the nature of the intervention, multiple stages, and time demands, the teacher decided to use a pretest/posttest measurement approach to determine treatment efficacy. Results revealed Jerry's pretest word reading accuracy averaged across passages was only 67%, and he improved to 98% accuracy at posttesting. In addition, Jerry did not miss a single comprehension question. These findings confirmed Jerry's word reading problems were executive in nature, and not the result of the more common phonological or phoneme–grapheme correspondence problems seen in many children with reading disability; however, note that these results are in part confounded by Jerry's medication treatment. While manipulating multiple variables simultaneously does not demonstrate sufficient experimental control in the tradition of behavior analysis, it is often what happens in the "real world" of collaborative problem solving. This flexible and adaptable problem-solving approach, one that uses both RTI and cognitive assessment techniques to identify and remediate learner difficulties, met the most important criterion: Jerry's learning and behavioral needs.

Implications

The literature on RTI models indicates that they alone can remediate the majority of students experiencing academic difficulties, especially in the early grades. The remaining percentage of nonresponders, those presumed to have a mismatch between their within-child characteristics and the instructional environment, would benefit from an individualized, comprehensive evaluation including cognitive processing. We have found little shared variance among global factors and subtests in both the construction of FSIQ (Fiorello et al., in press; Fiorello et al., 2001; Hale et al., 2001) and the prediction of achievement domains (Hale et al., 2001) for children with learning and other disabilities, attesting to the value of an idiographic rather than a nomothetic interpretive approach (Fiorello et al., in press; Hale et al., in press). Although Hale et al. (2001) showed that children with LD differed from typical populations in the prediction of word reading and reading comprehension, the achievement variance accounted for was relatively limited in the LD group. While one might argue that intelligence is less related to achievement for children with LD, collapsing disparate subtypes of LD into a heterogeneous sample could have additionally obscured findings (e.g., Rourke, 1994), especially since we know that children with LD have specific learning *deficits*, not *delays* (Francis, Shaywitz, Stuebing, Shaywitz, & Fletcher, 1994) and that reading disability subtypes have different cognitive, memory, language, motor, and attention/executive profiles (Berninger, 2002). If one subtype shows a positive correlation between the cognitive measures and an achievement outcome but the other subtype(s) have a negative relationship, the predictive validity for the combined group would be necessarily low.

Although a majority of children with reading problems will benefit from a phonological intervention, others (i.e., the other subtypes) will not respond. For nonresponders, a comprehensive CHT evaluation of cognitive processes could reveal processing strengths and deficits in preparation for developing, implementing, and evaluating targeted interventions. The findings reported here indicate that there are several subtypes of children with reading disabilities, and that for each subtype, a different combination of cognitive strengths and weaknesses lead to specific patterns of reading achievement. Although these subtypes could be identified through WISC-IV cognitive profiles, additional assessment using the CHT model should be used to confirm or refute these hypotheses (Hale & Fiorello, 2004), with individualized interventions designed to meet their needs. A variety of research has demonstrated that interventions based on individual cognitive and neuropsychological processes, including phonological awareness (e.g., Berninger, 2001; Torgesen et al., 1999), successive processing (Churches, Skuy, & Das, 2002), visual/orthographic processing (e.g., Berninger, 2001; Brunsdon, Hannan, Coltheart, & Nickels, 2002), attention training (e.g., Chenault, Thomson, Abbott, & Berninger, 2006; Solan, Shelley-Tremblay, Ficarra, Silverman, & Larson, 2003), working memory (Klingberg, Fernell, & Olesen, 2005), fluency/processing speed (Torgesen, Rashotte, & Alexander, 2001), and metacognitive and strategy instruction (Vauras, Kinnunen, & Rauhanummi, 1999) can be used to improve word reading and reading comprehension. These interventions lead not only to behavioral or performance changes but also to changes in brain function as well (Aylward et al., 2003; Demonet, Taylor, & Chaix, 2004; Papanicolaou et al., 2003; Shaywitz & Shaywitz, 2005; Simos et al., 2005). In addition, resources are now available to provide practitioners with multiple intervention strategies for cognitive processing deficits, such as Berninger's (2001) *Process Assessment of the Learner* (PAL), Hale & Fiorello's (2004) *School Neuropsychology*, Mather & Jaffe's (2002), *WJ III: Reports, Recommendations, and Strategies*, and Naglieri and Pickering's (2003) *Helping Children Learn*. When children do not respond to Tier 1 teaching or Tier 2 problem-solving interventions, the CHT model can be used to assess cognitive processing not only to identify children with LD but also to develop specifically designed individualized education programs that will tailor instruction designed to meet the needs of children with subtypes of reading disability.

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