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A multivariate model of early reading acquisition

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ABSTRACT
How similar are the cognitive and linguistic profiles of those children who easily learn to read? How similar are the profiles of those children who have difficulty learning to read? Do the profiles of successful and less successful readers vary among children 5–10 years of age? These were the questions that guided this study. Six core profiles were identified on four fluid reasoning to comprehension knowledge constructs previously found to be both theoretically and empirically linked to children's reading acquisition: auditory processing, crystallized ability, processing speed, and short-term memory. Cluster analysis was used to develop this taxonomy and the six-cluster solution was supported through cross-validation. The internal and external validity of the resulting profiles was favorable, suggesting homogeneous within-cluster membership and clear separation among the six core profiles. A summary of the defining characteristics for each profile is provided. The performance of children comprising different profiles was investigated on four external reading outcomes. These comparisons were conducted for each of the six age groups comprising the sample (i.e., 5–10 years) to assess whether the importance of certain score configurations varied as a function of the reading tasks required of children learning to read and those who are already readers. Results indicated that certain profiles were associated with greater success on external measures of reading achievement than other profiles. Trends across ages and differences among age groups are described.

Cognitive models, such as the Simple View of Reading, generally consider reading comprehension to be the product of two basic factors: word recognition and listening comprehension (Carver, 2000; Gough & Tunmer, 1986; Juel, 1994; Juel, Griffith, & Gough, 1986). Other factors, such as motivation or knowledge

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of certain reading strategies, no doubt influence reading comprehension. However, the primary influences on whether a reader normally comprehends a text are the degree to which the reader can accurately and quickly identify the printed words and the degree to which the reader can activate word meanings, or use syntax, text structures, and prior world knowledge, to perceive the meaning of the text.

Understanding of the nature of the sound–symbol relationship, which children do not often discover naturally in the course of learning to speak or listen, underlies the ability to decode (Liberman, 1998). Comprehending during reading relies on the same fundamental knowledge sources that would be used if one were listening to a conversation or a text being read aloud (e.g., word meanings, syntax, knowledge of structure; Gough, Hoover, & Peterson, 1996). According to this model of reading, the two components that are most important in reading acquisition are a child's word recognition and listening comprehension development. This study examined the cognitive and linguistic factors that are at the foundation of this growth.

In order to develop decoding ability, children first learn to identify printed words by recalling their letters and being able to attach sounds to those letters. For example, they may initially recall the word *cat* by remembering that it starts with the letter *c*. As they either intuit or receive instruction in how letters relate to sounds, learning that the letter *c* corresponds to /k/ may stimulate children's growth in decoding. As children attempt to sound out words, connecting spoken sounds to printed letters, their orthographic awareness of spelling patterns increases and these representations become more ingrained in their memory. When children read, they access information about the sounds and spellings of each word stored from previous encounters with it. After multiple encounters with each word, complete spellings of the word become amalgamated with the word's pronunciation and meaning and the reader is able to activate all this information about the word for automatic decoding of it (Ehri, 1992, 1998).

In addition to orthographic awareness, a key to linking letters to sounds is the ability to analyze and synthesize the phonological information in spoken words. Learning that words are made up of particular sounds and that individual letters or letter patterns are associated with certain sounds in the language is a significant level of phonological awareness that is important for decoding. Children need to distinguish sounds precisely enough so that they can be attributed to the corresponding graphemes (Ehri & Robbins, 1992). Phonological awareness, which includes not only phonemic awareness but also awareness of the linguistic units of syllables and of onsets and rimes, is important because it provides the basis for understanding the sound–symbol relationship that comprises alphabetic languages (Treiman & Zukowski, 1991). Research studies have shown that phonological awareness is strongly associated with the early development of word recognition (Adams, 1990; Juel, 1994; Juel et al., 1986; Share & Stanovich, 1995; Snow, Burns, & Griffen, 1998; Torgesen & Hecht, 1996; Wagner, Torgesen, & Rashotte, 1994; Yopp, 1995).

Phonological awareness is likely associated with early oral language (Bowey & Patel, 1988; Bryant, Bradley, & MacLean, 1990). As written language is a graphic representation of spoken language, oral language is a significant pre-

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cursor to reading and, in fact, is correlated with later reading success (Noonan, Hildebrand, & Yackulic, 1997; Snow et al., 1998). As children acquire a greater number of words in their spoken vocabulary, they begin to develop ways to categorize the words for more efficient retrieval. This categorization may foster phonological awareness (Goswami, 2000; Menyuk & Chesnik, 1997; Metsala & Walley, 1998).

Oral language not only affects children's ability to decode, it plays its most prominent role by influencing listening comprehension ability. In the Simple View of Reading equation, children must develop effective listening comprehension in order to make meaning of the words that they decode. Listening comprehension, fostered by oral language communication between children and their caretakers from birth through childhood, involves knowledge of concepts, vocabulary, and world experiences, as well as knowledge-based reasoning (Hart & Risley, 1995; Snow, Barnes, Chandler, Goodman, & Hemphill, 1991). Given perfect word recognition, reading comprehension comes to rest on the foundation of knowledge and skill inherent in listening comprehension.

PUTTING THE SIMPLE VIEW OF READING INTO A LARGER COGNITIVE FRAMEWORK

There are at least two cognitive–linguistic mediators that have been identified as affecting the acquisition of orthographic knowledge, phonological awareness, and the orthographic knowledge required in word recognition and listening comprehension. These are working memory and processing speed (Baddeley, 1986; John, 1998; Joshi & Aaron, 2000; Lovett, 1987; Manis, Doi, & Bhadha, 2000; Naesland & Smolkin, 1997; Oakhill & Kyle, 2000; Watson & Willows, 1995; Wolf & Bowers, 2000). For example, both affect the acquisition of oral language as it is necessary for children to hold the identifier in their working memory as they use their processing capabilities to determine the referent and link the referent to the identifier. Similarly, children must coordinate visual–spatial and phonological information in working memory as they decode words.

It is likely that the aforementioned cognitive functions and sources of knowledge operate in concert rather than in isolation. Take, for example, the case of the mother of a child who says, "There goes the doggy." As the family dog passes through the room, the child must hold the words he or she heard as well as the image of the dog that just passed by in memory as he or she processes which word ("doggy") should be attributed as the identifier of the animal that just walked across the room. Through such a process, the child builds lexical knowledge. When the child begins to learn to read the word *dog,* similar working memory and processing capabilities are required. In reading the word dog, the child must hold each of the letters in order, as well as the phonological pronunciation of each of the letters, in working memory as he or she processes the fact that the sounds of the letters *d, o, g,* when blended together, are pronounced as dog. In this process, the child calls upon his or her orthographic knowledge of the letters and phonological knowledge of the sounds of the letters. Finally, the child must use his or her lexical knowledge of what the word

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dog represents to make meaning from the pronunciation of the sounds of the letters in order to comprehend what he or she has just read.

Although an understanding of how these causative agents function is important, learning to read is a multivariate phenomenon that requires joint consideration of these processes (i.e., children may have strengths or weaknesses in more than one area). One child, for example, may have a core deficit in phonological awareness but strong listening comprehension and oral vocabulary. Another child may have a core deficit in phonological awareness in conjunction with a weak oral vocabulary. Yet another child may have a core deficit in phonological awareness that is exacerbated by overall slow processing speed. As a result, it is important to develop models that integrate the full network of relationships that exist among these abilities in order to investigate their joint influence on reading outcomes. Understanding the complex network of these abilities and their influence on emergent readers will increase our theoretical understanding and be useful for instruction.

Many theories of human abilities have been proposed over the years in an attempt to explain individual differences. The most promising theory seems to be based on the Horn–Cattell fluid reasoning to comprehension (Gf–Gc) model (Ysseldyke, 1990). This model is said to "offer the most well-founded and reasonable approach to an acceptable theory of the structure of cognitive abilities" (Carroll, 1993, p. 62). Accordingly, it provides a strong foundation for understanding the cognitive and psycholinguistic characteristics of learning to read. The Gf–Gc model has been described as a theory of several intelligences (Horn & Noll, 1997) that currently comprises nine broad abilities (Horn, 1991): fluid reasoning (Gf), comprehension knowledge (Gc), visual processing (Gv), auditory processing (Ga), correct decision speed (CDS), processing speed (Gs), short-term memory (Gsm), long-term retrieval (Glr), and quantitative ability (Gq). This study investigated children's profiles on four of the Gf–Gc constructs (i.e., Ga, Gc, Gs, and Gsm) that appear to be of specific importance to children's reading acquisition.

Auditory processing (Ga), or phonological awareness, involves the understanding of auditory patterns and is particularly important for language development (Woodcock, 1990). In a series of structural models designed to investigate the relationships between the Gf–Gc factors and various reading and writing outcomes in a sample comprised of school-aged children and adults, auditory processing was found to yield a greater structural relationship (SR) with basic reading skills (SR = 0.40) than any of the other Gf–Gc abilities. It was also found to influence reading comprehension (SR = 0.20), but to a somewhat lesser degree than basic reading skills (McGrew, Werder, & Woodcock, 1991). Another investigation considered the relationships between auditory processing and achievements as a function of age by using a series of regression analyses (McGrew, 1994). Relationships among these variables were found to vary considerably when standardized regression weights were plotted across the lifespan (i.e., 5–70+ years of age). The relationship between auditory processing and basic reading skills was strongest in the early years (i.e., age 5; $B \approx 0.30$) and showed a steady decline to about age 45 ($B \approx 0.02$) before climbing back up to age 70 ($B \approx 0.15$). The relationship with reading comprehension was also stronger for

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younger children ($B \approx 0.18$) and steadily decreased to the point where little relationship was observed beyond age 20 ($B \approx 0$).

Crystallized ability (Gc), or what some refer to as comprehension knowledge (McGrew et al., 1991), consists of world knowledge and experience. It also includes knowledge-based reasoning and judgment (Woodcock, 1990). Structural model studies demonstrated that this factor had a greater influence on reading comprehension (SR = 0.58) than other Gf–Gc factors, and it was also found to influence basic reading skills (SR = 0.30; McGrew et al., 1991). Unlike other Gf–Gc factors, these relationships are weaker for younger children (i.e., age 5) and rapidly increase with age (McGrew, 1994). For example, standardized beta weights plotted as a function of age revealed the weakest relationships between comprehension knowledge and both reading comprehension and basic reading skills ($B \approx 0.18$) for 5-year-old children. This association between comprehension knowledge and reading comprehension showed a steady increase to age 35 ($B \approx 0.70$) before declining for adults aged 50 and greater ($B \approx 0.60$). The relationship between comprehension knowledge and basic reading skills was found to increase to about age 65 ($B \approx 0.71$).

Text comprehension requires children to have knowledge of the concepts and world described by words plus the ability to draw inferences from their existing knowledge. Knowledge of concepts and the world is especially critical when the texts children read are informational in nature. As Juel's (1994) longitudinal study demonstrated, even successful early decoders started to fail in the upper elementary grades if they lacked the world knowledge to understand texts. It is important to remember that Grade 4 often represents a transition in literacy, a point at which informational text begins to assume an ever-increasing role in reading. Informational texts can be difficult for children because authors of these texts generally assume a good deal of background knowledge.

In comparison to ordinary conversations, less common words are employed in both informational and narrative texts. In narrative texts, the unexpected word or event may actually be one of the devices authors use to keep the reader interested. As a field, we have increased children's exposure to interesting, but difficult, literate vocabulary by increasing the use of children's literature in primary classrooms. In everyday conversation, a child may tell her friend that her folks were "fighting." In a narrative text, however, the child might encounter "bickering" (Cleary, 1985).

Reasoning and inference (i.e., putting things together) based on existing knowledge is also required for successful reading of grade-appropriate text. Text comprehension is an interaction between what the reader knows about a topic and the information the text provides (Kintsch, 1988). Writers of both narrative and informational texts normally make assumptions about the reader's knowledge base, but these assumptions can be wrong. A reader may not have the background knowledge, may not know how to finesse it, and may withdraw from engagement with the text. To read both informational and narrative texts, the reader must activate background knowledge, supply inferences to fill in what the author does not say, and simply reflect on what is being read.

Text is normally nonredundant or at least highly parsimonious. Inferences are continually required to make sense of texts. Even a brief note, such as "Clean

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up your room," requires the inference by the reader that the note is addressed to her, that the writer probably wants a quick response, and that the writer assumes the reader knows what is to be picked up. In fact, if a speaker or a writer fills in too many details, we are likely to accuse him or her of being ponderous and boring. Inferences require a strong knowledge base, as well as attention, motivation to make sense of a text, and active reasoning about what one is reading.

Last, processing speed (Gs) and short-term memory (Gsm) appear important to basic reading skills and reading comprehension (McGrew, 1994). Processing speed involves the ability to maintain focus and work quickly through automatic cognitive tasks. Processing speed was found to yield a notable influence on reading comprehension (SR = 0.11) and basic reading skills (SR = .16; McGrew, 1994; McGrew et al., 1991). When examined as a function of age, relationships between processing speed and basic reading skills were stronger for younger children ranging in age from 5 to 10 ($B \approx 0.28$–0.15) and continued to dip to about age 20 ($B \approx 0.13$), beyond which little change was observed until age 65. Reading comprehension also demonstrated stronger relationships with processing speed for younger children between the ages of 5 and 10 years ($B \approx 0.25$–0.15) showing a slow but steady decline to age 70 ($B \approx 0$; McGrew, 1994).

Due to the many tasks required of the successful reader, some of the processes must become automatic. For example, when children have letters, syllables, and word recognition at a level of automaticity, it allows them to place greater attention on comprehending what is being read. Short-term memory, or working memory, involves the ability to maintain a limited amount of information in immediate awareness for use within a short period of time. It demonstrated moderate relationships with basic reading skills that increased with age from 5 years ($B \approx 0.10$) to about 40 years ($B \approx 0.20$). Its relationship with reading comprehension was slightly weaker in the early years ($B \approx 0.08$) but increased with age to about 24 years ($B \approx 0.18$; McGrew, 1994).

Short-term memory is involved in remembering word links between letters and sounds as well as the spelling of "irregular" words (e.g., come, of). Individuals with short-term memory deficits have greater difficulty recalling information, which in turn causes greater difficulty when attempting to comprehend sentences. This difficulty is particularly problematic with complex sentence structures (Mather, 1991).

Given this complex array of factors involved in successful reading, children face a formidable learning task. They must develop the ability to analyze and synthesize phonemic information in spoken words (Ga). They must recall specific orthographic patterns (e.g., the *ea* in *bead* signals that the word should be pronounced with a long instead of short *e* vowel sound, distinguishing the word from *bed*). They must gain sufficient world knowledge in order to understand what is being read, and they must be active readers who bring everything they know to bear upon what they read and then expand upon it to accommodate new information (Gc). Children with Gs and/or Gsm deficits will likely experience even greater challenges as a result of needing to concentrate on basic skills that are not yet automatic and difficulties recalling and manipulating previously learned information, respectively.

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Because many beginning readers have difficulty in more than one area of reading, it is important to develop models that explain how the processes mentioned earlier operate in combination to explain reading acquisition difficulties in order to improve diagnosis and instruction. This study examined children's profiles on measures of Ga, Gc, Gs, and Gsm as they relate to literacy outcomes. A model was developed through cluster analysis to provide a unified framework of how these constructs operate in concert by accounting for the multivariate aspects of children's abilities. Cluster analysis has been used throughout numerous disciplines to understand the nature of individual differences related to dyslexia (Satz, Morris, & Fletcher, 1985), language (Beitchman, Hood, Rochon, Peterson, Mantini, & Majumdar, 1988; Fegans & Appelbaum, 1986; Speece, Roth, Cooper, & LaPaz, 1999), learning disabilities (Konold, Glutting, & McDermott, 1997; McKinney & Speece, 1986; Speece, McKinney, & Appelbaum, 1985), and neuropsychology (Morris, Blashfield, & Satz, 1981). This procedure allowed us to account for the heterogeneous nature of children's reading abilities and identify homogeneous subgroups of children that displayed similar patterns of strengths and weaknesses.

The four constructs were measured with six tests that were treated as profiles. Profiles are integrated sets of test scores that are defined by three elements: level, shape, and scatter (Cronbach & Gleser, 1953). Treating test scores as integrated profiles provides many benefits. Most notable is that multivariate methods of evaluating profiles account for the full network of relationships among abilities (Sternberg, 1984) and provide greater insight into the nature and complexity of human ability, thereby providing greater diagnostic precision (Glutting, McDermott, & Konold, 1997).

A large nationally standardized sample was used to identify the most common reading profiles of children on measures of Ga, Gc, Gs, and Gsm. Cross-validation was incorporated into the analysis, and the internal and external validity of the resulting profiles was also investigated. Children within profiles were then compared to children in other profiles on various reading outcomes to determine which profiles were most likely to be associated with successful readers. These comparisons were conducted at six age levels (i.e., 5–10 years).

Several questions were of particular interest: (a) What are the most common profiles of important reading abilities? (b) Which profiles are associated with success in reading, and what patterns are likely to result in reading acquisition difficulty? (c) Are the same profiles that are associated with success in one aspect of reading (e.g., word recognition) also associated with success in other reading areas (e.g., comprehension)? (d) Are certain profiles more likely to result in reading success at a given age, or do they remain invariant across age?

METHODS

Subjects

One thousand six hundred and four children, ranging in age from 5 to 10 years (M = 7.8; SD = 1.6), were selected from the Woodcock Diagnostic Reading Battery (WDRB; Woodcock, 1997) standardization sample. The sample was

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stratified in accordance with 1980 (and later) U.S. census reports on the variables of race (Anglo American, 81.2%; African American, 15%; Native American, 0.9%; and Asian, 2.8%), gender (male, 50.8%; female, 49.2%), and origin (Hispanic, 9.7%; non-Hispanic, 90.3%).

Instrumentation

The Woodcock–Johnson Tests of Cognitive Ability (WJ-R COG; Woodcock & Johnson, 1989) are operational representations of the Horn–Cattell Gf–Gc theory (Woodcock, 1990; Ysseldyke, 1990). Some of the same tests on the WJ-R COG are also located on the WDRB (Woodcock, 1997) for convenience to those whose primary interest is in reading. The WDRB comprises 10 tests (M = 100, SD = 10), 6 of which can be combined to measure the four Gf–Gc abilities currently under investigation (i.e., Ga, Gc, Gs, Gsm; Woodcock, 1990).

Variable selection in cluster analysis is important to maximize subtype differences (Morris, Blashfield, & Slatz, 1981). Therefore, the solution was weighted to reflect the importance of the constructs to reading success. Two measures of the constructs that were previously found to yield the strongest relationships with reading (i.e., Ga and Gc) were included in the analysis. In addition, one measure of each of the remaining two constructs (i.e., Gs and Gsm), which were previously found to yield notable, but somewhat smaller, relationships with reading in the early years, was included.

The remaining four tests on the WDRB provide measures of basic reading skills (Letter–Word Identification, Word Attack) and reading comprehension (Reading Vocabulary, Passage Comprehension; McGrew, Werder, & Woodcock, 1991). These achievement-oriented tests served as reading outcome variables for determining which profiles were most likely to be associated with reading success. A brief description of these measures is provided next. Descriptions were adopted in part from the WDRB *Examiner's Manual*, and factor loadings can be found in Woodcock (1990). The reported factor loadings that follow represent the median value obtained across nine data sets in which independent confirmatory factor analyses were conducted.

Auditory processing was assessed with two subtests, Incomplete Words and Sound Blending, which, when combined, also measure phonological awareness. Incomplete Words requires children to identify words with one or more missing phonemes. This test yielded a median factor loading of 0.55 on Ga. Sound Blending provides a measure of phonological synthesis by asking children to consider words presented to them in parts and respond with the whole word. Sound Blending provides a slightly better measure of Ga than Incomplete Words, with a median factor loading of 0.69.

Crystallized ability/comprehension knowledge was also assessed with two subtests, Oral Vocabulary and Listening Comprehension. Oral Vocabulary measures knowledge of word meaning and has a median factor loading of .61 on Gc. This test taps children's ability to recall appropriate words in context and provides information pertaining to receptive and expressive vocabulary. Listening Comprehension evaluates children's prior knowledge with simple verbal analogies and associations and then progresses to higher level comprehension involving reasoning. The median factor loading of this test on Gs was 0.66.

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Table 1. *Descriptive statistics for WDRB clustered variables and reading achievement outcome measures*

	M	*SD*
Clustered variables		
Memory for Sentences	101	16
Visual Matching	100	16
Incomplete Words	101	15
Sound Blending	101	16
Oral Vocabulary	102	16
Listening Comprehension	102	16
Achievement measures		
Letter–Word Identification	101	16
Word Attack	100	17
Reading Vocabulary	102	15
Passage Comprehension	102	15

The total number of subjects was 1,604.

Processing speed was measured with Visual Matching. Visual Matching measures visual processing by requiring children to identify and mark two identical numbers in a row that contains six numbers. This test provides an exceptionally good measure of Gs with a median factor loading of 0.84.

Short-term memory was measured with Memory for Sentences. Memory for Sentences loads on Gsm with a median factor loading of 0.55. In this task, the child makes use of sentence meaning to aid retrieval.

Two measures of basic reading skills and reading comprehension were used as outcome measures for comparing the performance of children with different profiles. Basic reading skills were measured with Letter–Word Identification and Word Attack. Letter–Word Identification requires children to identify symbols, letters, and words (median factor loading = 0.93). Word Attack measures the ability to pronounce printed, unfamiliar letter strings by applying phonic and structural analysis skills (median factor loading = 0.79). Reading Comprehension was measured with Reading Vocabulary and Passage Comprehension. Reading Vocabulary evaluates children's ability to read words and provide appropriate meaning to them (median factor loading = 0.93). Passage Comprehension requires children to respond with an appropriate word for the context of the passage they are reading. These items require the use of a variety of vocabulary and comprehension skills to respond (median factor loading = 0.78).

DATA ANALYSES AND RESULTS

Means and standard deviations for the six tests comprising the constructs of phonological awareness, oral comprehension, and reading aptitude used to identify normative profiles through cluster analysis are presented in Table 1. The

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clustering strategy we adopted was similar to the one used elsewhere for identifying normative profiles (Glutting & McDermott, 1990; Glutting et al., 1997; Konold et al., 1997; Konold, Glutting, McDermott, Kush, & Watkins, 1999; McDermott, Glutting, Jones, & Noonan, 1989), as described in McDermott (1998). This procedure involved three steps. In the first step, the total sample (N = 1,604) was randomly divided into four equal samples (N = 401), and Ward's (1963) hierarchical–agglomerative procedure was performed on a Euclidean distance matrix that is sensitive to level, shape, and scatter. Decisions regarding the number of clusters to retain within each of the four samples were based on a number of indices: pseudo-F (Calinski & Harabasz, 1985), pseudo t^2 (Duda & Hart, 1973), and R^2. This step also utilized a "trim" procedure that removed a maximum of 2% of the outlier cases from consideration in the analysis.

Information from the clusters identified in Step 1 was pooled to form an overall similarity matrix, which was used for Step 2. Thus, Step 2 clustering began with a proximity matrix whose diagonal elements held error sums of squares statistic values for respective Step 1 clusters, with off-diagonal elements corresponding to potential error sums of squares for merging each pair of first-stage clusters. Ward's method was employed on the resulting similarity matrix to assess the extent to which cluster profiles from subsamples of the data matched those found for the total sample (i.e., replication). Each of these statistical indices was again considered when determining the number of clusters to retain at Step 2. Steps 1 and 2 led to the identification of six clusters, each of which yielded a 100% replication rate. This replication rate indicates that each of the profiles identified in the four subsamples also emerged when the entire sample was utilized.

Group centroids from the step 2 solution served as starting partitions for the stage 3, iterative partitioning analysis conducted using K-means passes. This third stage was necessary because hierarchical–agglomerative procedures (steps 1 and 2) do not allow subjects to shift clusters after their original assignment, despite the fact that they may fit better in a different profile later in the solution. By contrast, iterative partitioning procedures allow subjects to migrate to neighboring clusters, following identification of the number of suspected clusters (steps 1 and 2), and they generally result in tighter solutions.

Mean profile configurations are presented in Table 2 and illustrated in Figure 1. The six profiles represent natural variation of reading abilities and are typical of what we would expect among children between the ages of 5 and 10 years. Profiles 1, 2, and 4 were defined by general reading ability. That is, they are flat, revealing little indication of relative strengths or weaknesses among subtests. Profile 1 was characterized by average reading ability, Profile 2 by low reading ability, and Profile 4 by above average reading ability. The remaining three profiles (3, 5, and 6) demonstrated noteworthy patterns of dips and rises. Each of these three profiles was approximately centered on average ability. However, they also reflected different strengths that distinguished them. Profile 3 reflected strengths in Oral Vocabulary, Listening Comprehension (measures of Gc), and Memory for Sentences (Gsm); Profile 5 demonstrated elevated

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Table 2. *Standard score means and standard deviations for the WDRB core profile types*

Profile Type	Memory for Sentences	Visual Matching	Incomplete Words	Sound Blends	Oral Vocabulary	Listening Comprehension
1. Average reading ability	95 (10)	93 (9)	96 (10)	95 (10)	93 (9)	94 (8)
2. Below-average reading ability	82 (10)	87 (13)	86 (11)	81 (13)	82 (9)	82 (11)
3. Average reading ability with strengths in Gc and Gsm	110 (11)	97 (11)	103 (10)	99 (9)	113 (10)	114 (11)
4. Above-average reading ability	120 (13)	116 (13)	112 (12)	121 (12)	122 (12)	119 (13)
5. Average reading ability with strengths in Ga	103 (10)	96 (10)	112 (11)	115 (11)	104 (9)	105 (10)
6. Average reading ability with elevated Gs	97 (10)	115 (9)	100 (10)	100 (11)	101 (10)	101 (11)

Note: The tabled values are rounded to whole numbers for ease of presentation. Standard deviations are in parentheses.

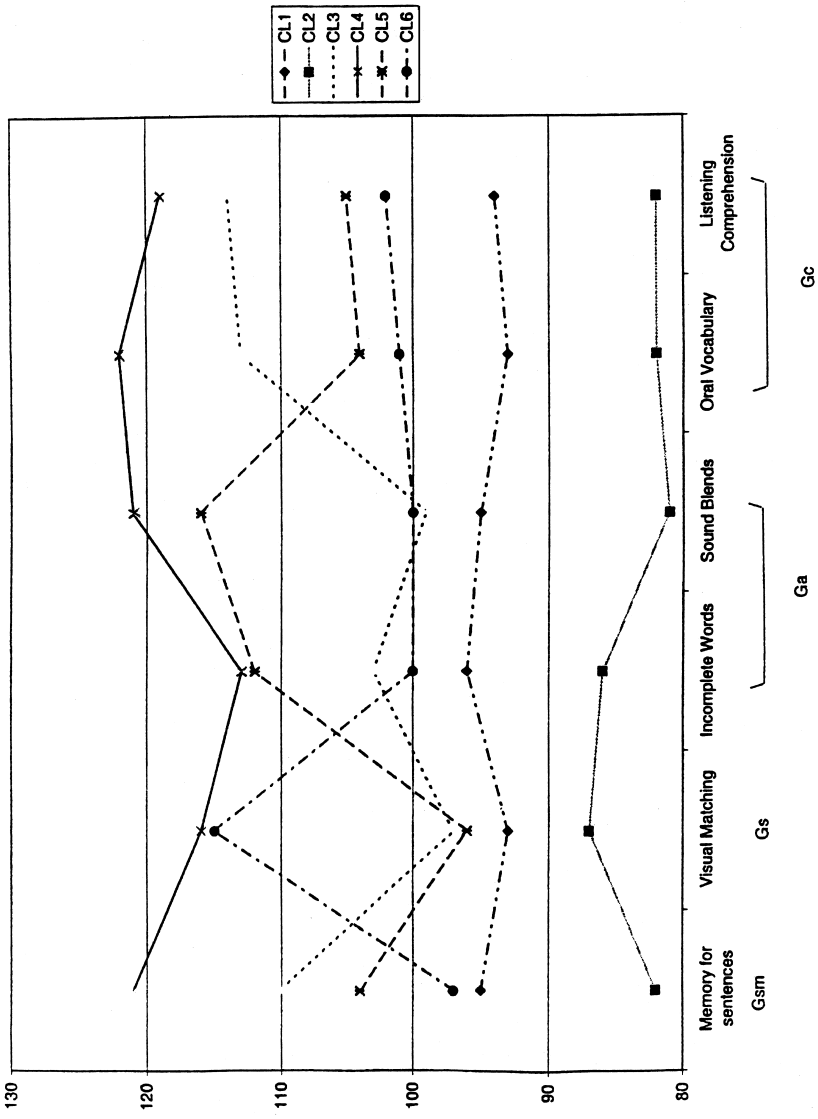


Figure 1. The normative reading ability profiles.

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Table 3. *Psychometric properties of the WDRB core profiles*

Cluster No.	Population Prevalence (%)	Internal Profile Cohesion (*H*)	External Isolation (*Rp*)	Independent Replications Across Four Blocks (%)
1	25	0.77	0.31	100
2	11	0.68	0.01	100
3	15	0.73	0.46	100
4	13	0.58	0.37	100
5	16	0.75	0.32	100
6	17	0.74	0.42	100
Averages		0.71	0.32	100

scores on Incomplete Words and Sound Blending (measures of Ga); and children in Profile 6 demonstrated strengths on Visual Matching (Gs).

Prevalence rates, internal cohesion, external isolation, and profile replication rates are presented in Table 3 for each of the six clusters. The average *H* coefficient (Tryon & Bailey, 1970) of 0.71 provides evidence in support of homogeneous within-cluster representation. External isolation refers to the extent to which clusters differ from one another in multivariate space. An examination of Table 3 provides evidence in support of the six-cluster solution through external isolation. That is, the average *Rp* value of 0.32 only slightly exceeds the a priori criterion of $Rp < 0.30$, indicating good separation between clusters. All profiles demonstrated a 100% replication rate for the absorption of step 1 clusters from a given block into the final taxonomy.

An overview of the six cluster profiles is provided next. This summary also considers the demographic representation of gender and age within each cluster. Observed demographic proportions within each cluster were compared to what would be expected if children comprising different demographic groups were proportionately distributed across the six profiles according to their representation in the total sample ($N = 1{,}604$). For example, the total sample ($N = 1{,}604$) was comprised of 50.8% males and 49.2% females. Profile 1 contained 25% of the total sample ($N = 401$). Thus, we would expect 50.8% of this number to be males and 49.2% to be females. This procedure tested for violations of this hypothesis within each profile. Two-tailed standard error of proportional difference tests were made for all possible pairwise comparisons within each profile. Type I error rates were controlled through the use of Bonferroni adjustments. Results demonstrated that children's age was *not* statistically different from population expectancy within any of the six clusters, suggesting that these reading ability profiles were not differentially influenced by age. The prevailing composition of each profile type described below considers only those demographic variables for which significant differences were obtained ($p < .05$).

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Profile Types

1. Average reading ability (prevalence = 25%). Children in this cluster demonstrated a relatively flat profile, with scores reflecting average reading ability. This type demonstrated the highest rate of prevalence.

2. Below-average reading ability (prevalence = 11%). This profile demonstrated the lowest rate of prevalence. Similar to Profile 1, it was relatively flat with no remarkable patterns of dips or rises across subtests.

3. Average reading ability with Gc and Gsm strengths (prevalence = 15%). Elevations were observed on three of the six tests used to form clusters, two of which measured Gc (Oral Vocabulary and Listening Comprehension) and one of which measured Gsm (Memory for Sentences). There were more males and fewer females than expected in this cluster.

4. Above-average reading ability (prevalence = 13%). Similar to Profiles 1 and 2, Profile 4 failed to demonstrate any noteworthy dips or rises. This profile was the highest in terms of elevation (i.e., general ability), and it failed to demonstrate any unusual demographic representation.

5. Average reading ability with strengths in Ga (prevalence = 16%). Children with this profile obtained average scores on most tests but had definitely elevated scores on measures of Ga (i.e., Incomplete Words and Sound Blending).

6. Average reading ability with elevated Gs (prevalence = 17%). Of the three profiles demonstrating average ability with notable elevations, Profile 6 yielded a strength on a measure of Gs (i.e., Visual Matching). There were fewer males and more females than expected in this profile.

The performance of children comprising different profiles was investigated on four reading outcome measures. This procedure served two purposes. First, it allowed us to further substantiate the external validity of the six clusters by demonstrating that children within profiles scored differently on reading outcome measures than children in other profiles. Second, it allowed us to investigate which profiles were associated with success in reading and assess whether the importance of certain score configurations varied as a function of the increasingly demanding reading tasks required of growing children.

We anticipated several reading outcome differences among children with different profile configurations. First, we expected that children comprising Cluster 4 (above average ability) would perform better than children comprising the other five profiles as a result of their elevated score configurations on all four cluster-defining Gf–Gc constructs. Second, we expected that children in Cluster 2 would have the most difficulty with reading tasks, as a result of their depressed Gf–Gc score configurations. Third, following the work of McGrew (1994), we expected auditory processing to play an important role in reading acquisition skills for children 5–10 years of age. Fourth, we anticipated that crystallized ability and short-term memory would become a contributing factor to reading success following years 5 and 6, and fifth, we expected that processing speed would be an important predictor of reading success in the early years.

Means and standard deviations for the four achievement measures are provided in Table 1 for the entire sample. In addition, means for each achievement variable by age and cluster are reported in Table 4. A multivariate analysis of

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Table 4. *Mean achievement scores by age within each cluster and effect sizes for achievement comparisons between clusters by age*

Age and Reading Achievement	Cluster Number						Effect Size R^2
	1	2	3	4	5	6	
5. LWI	87.82	82.59	98.50	115.72	104.50	100.39	0.371
WA	83.86	80.47	81.25	106.11	108.06	85.09	0.314
RV	94.21	89.29	94.94	108.50	108.31	99.43	0.249
PC	105.61	100.76	107.50	118.94	110.25	109.83	0.098
$N = 118$							
6. LWI	93.31	84.20	103.87	118.33	105.65	104.93	0.324
WA	86.79	81.28	94.67	112.13	99.68	97.98	0.287
RV	91.01	84.98	101.38	115.25	104.45	98.27	0.317
PC	92.54	87.35	102.20	115.50	104.53	102.13	0.254
$N = 291$							
7. LWI	97.41	88.48	100.86	121.17	107.68	112.19	0.446
WA	94.95	85.48	99.76	121.09	109.43	109.81	0.463
RV	95.88	85.69	106.66	120.83	106.68	110.78	0.483
PC	97.38	87.59	102.31	118.49	106.45	107.53	0.392
$N = 228$							
8. LWI	97.01	85.90	106.35	118.00	105.52	104.33	0.403
WA	96.76	85.55	104.39	117.44	110.78	102.20	0.364
RV	97.23	88.45	111.78	122.61	106.30	104.04	0.584
PC	97.37	87.71	110.43	122.54	107.53	104.20	0.446
$N = 325$							
9. LWI	92.67	83.28	99.27	116.64	101.48	100.87	0.434
WA	94.45	84.44	100.39	117.55	105.74	103.63	0.330
RV	94.63	83.25	107.78	118.33	104.98	101.98	0.527
PC	94.61	84.69	106.95	118.38	103.74	104.27	0.417
$N = 300$							
10. LWI	96.65	82.47	106.92	116.23	102.80	103.52	0.307
WA	97.68	82.56	107.26	116.42	105.58	103.79	0.313
RV	94.78	84.69	111.61	120.55	103.04	102.15	0.482
PC	94.10	82.94	109.10	118.29	104.96	103.48	0.427
$N = 303$							

Note: LWI, Letter–Word Identification; WA, Word Attack, RV, Reading Vocabulary; PC, Passage Comprehension. Sample size discrepancy between the number of observations reported in the subject section ($N = 1{,}604$) and the total number in this table ($N = 1{,}565$) is a result of the trim procedure used in the clustering algorithms.

variance (MANOVA) was conducted at each age level to assess whether scores from the four achievement measures, Letter–Word Identification, Word Attack, Reading Vocabulary, and Passage Comprehension, varied across the six profiles. A Bonferroni adjustment was made to control Type I error rates across age groups (i.e., $0.05 \div 6 = 0.008$). MANOVA results indicated that scores on the four achievement measures varied significantly as a function of the six profile types across all six age groups (all ps $< .001$).

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Follow-up comparisons were completed using four one-way ANOVA within each age level. Each reading achievement served as a dependent variable. Type I error rates among the four comparisons and each of the six age groups were controlled through Bonferroni adjustments (i.e., $4 \times 6 = 24$; $0.05 \div 24 = 0.002$). Twenty-three of these 24 tests were found to yield statistically significant results, all ps $< .001$. All statistically significant results also demonstrated large effect sizes (i.e., 0.25 or greater) following Cohen's (1988) interpretive guidelines. The sole exception occurred for 5-year-old children, for whom no profile differences were found on the Passage Comprehension test ($p = .04$). These results also add to the external validity of the six clusters by yielding significant differences among profiles on all four reading achievement measures.

In order to identify profiles that were most important to success on a given reading outcome, Tukey tests were conducted within each age group. The harmonic mean procedure was used to account for unequal sample sizes. Results lend empirical support to the first two aforementioned hypotheses regarding the performance of children in Clusters 4 and 2, above-average reading ability and below-average reading ability, respectively. Namely, children in Cluster 4 demonstrated statistically greater scores than all other children on the reading outcomes of Letter–Word Identification, Word Attack, Reading Vocabulary, and Passage Comprehension with few exceptions. These exceptions occurred at ages 5 and 8. At age 5, children comprising Cluster 4 did not perform statistically better than children in Cluster 5 (Ga) on Letter–Word Identification or Word Attack. Five-year-old children in Cluster 4 also failed to demonstrate statistical differences in comparison to children in Clusters 5 or 6 on Reading Vocabulary. The final exception occurred among children 8 years of age: children in Cluster 4 were not statistically different from children comprising Cluster 5 on Word Attack.

The second hypothesis noted above was that children in Profile 2 would have the most difficulty with reading tasks as a result of their depressed score configurations. This expectation was also empirically supported. Children in this profile failed to demonstrate statistically greater scores than children with any other profile type on all four reading outcomes without exception. This finding held across all six age groups.

The importance of Gf–Gc measures used to define the remaining profiles (i.e., Profiles 1, 3, 5, and 6) varied as a function of developmental age and the reading outcome under consideration. Thus, profile comparisons for each statistically significant ($p < .05$) reading outcome are summarized below by age. Given the trends of Profiles 4 and 2 across age groups noted above, these profiles are not considered in the results that follow. The remaining four profiles left for consideration were previously defined by average ability (i.e., Profile 1) and average ability with notable Gf–Gc strengths (i.e., Profile 3: Gc and Gsm; Profile 5: Ga; and Profile 6: Gs. These profile comparisons provide the most insight concerning the reading ability patterns that are likely to result in reading success at a given age. Because Profile 1 represents a relatively flat profile of average ability, it provides a good baseline for comparing the relative strengths found in Profiles 3, 5, and 6, which are otherwise also defined by average ability. For ease of presentation, profiles will be referred to by their defining

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characteristics (noted previously) rather than their Gf–Gc abbreviation. Following these profile comparisons by age, the remaining three hypotheses will be addressed. All differences noted here were statistically significant as determined by Tukey tests ($p < .05$).

Age 5. Children with auditory processing/phonological awareness strengths (Profile 5) demonstrated statistically greater scores than children of average ability with no secondary strengths (Profile 1) on measures of Letter–Word Identification, Word Attack, and Reading Vocabulary. These children also demonstrated statistically greater scores than children with strengths in crystallized ability and short-term memory (Profile 3) or processing speed (Profile 6) on Word Attack than children with crystallized ability and short-term memory strengths on Reading Vocabulary. No notable differences were found among children with strengths in crystallized ability and short-term memory, processing speed, and average ability with no secondary strengths.

Age 6. Children with auditory processing/phonological awareness (Profile 5) or processing speed (Profile 6) strengths performed statistically better than children of average ability with no secondary strengths (Profile 1) on all four reading outcome measures. Children with crystallized ability and short-term memory strengths (Profile 3) performed statistically better than children of average ability with no secondary strengths on Letter–Word Identification and Passage Comprehension but failed to perform statistically better on Word Attack or Reading Vocabulary.

Age 7. The pattern of results for children with auditory processing/phonological awareness (Profile 5) and processing speed (Profile 6) strengths was similar to that found for 6-year-old children. Namely, children with these two profiles also performed statistically better than children of average ability with no secondary strengths (Profile 1) on all four reading outcome measures. These children also performed statistically better on Word Attack than children with strengths in crystallized ability and short-term memory (Profile 3). Moreover, children with processing speed strengths performed statistically better than children with strengths in crystallized ability and short-term memory on Letter–Word Identification. Children with crystallized ability and short-term memory strengths only performed statistically better than children of average ability with no secondary strengths on Reading Vocabulary.

Age 8. Children with auditory processing/phonological awareness strengths (Profile 5) continued to demonstrate statistically greater achievements than children of average ability with no secondary strengths (Profile 1) on all four reading outcomes. These children were also found to yield statistically greater scores than children with processing speed strengths (Profile 6) on Word Attack. Nonetheless, children with strengths in processing speed did demonstrate statistically greater scores than children of average ability with no secondary strengths on the remaining three measures of Letter–Word Identification, Reading Vocabulary, and Passage Comprehension. The most notable change from earlier age

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groups concerned the behavior of children with crystallized ability and short-term memory strengths (Profile 3). These children performed statistically better than children of average ability with no secondary strengths on all four reading outcomes and also better than children with either auditory processing/phonological awareness or processing speed strengths on Reading Vocabulary.

Age 9. Children with either auditory processing/phonological awareness (Profile 5) or processing speed (Profile 6) strengths performed statistically better than children of average ability with no secondary strengths (Profile 1) on all four reading outcome measures. Similarly, children with crystallized ability and short-term memory strengths (Profile 3) performed statistically better than children of average ability with no secondary strengths on three of the four reading outcome measures (i.e., Letter–Word Identification, Reading Vocabulary, and Passage Comprehension).

Age 10. Children with crystallized ability and short-term memory strengths (Profile 3) performed statistically better than children with any other profile type at this age group. These children demonstrated statistically higher scores than children of average ability with no secondary strengths (Profile 1) on all four reading outcome measures and also outperformed children with auditory processing/phonological awareness (Profile 5) and processing speed (Profile 6) strengths on Reading Vocabulary. Children with auditory processing strengths performed statistically better than children of average ability with no secondary strengths on measures of Word Attack, Reading Vocabulary, and Passage Comprehension, whereas children with processing speed strengths only performed better than children of average ability with no secondary strengths on measures of Reading Vocabulary and Passage Comprehension.

Findings

In sorting through these cluster comparisons by age, our last three hypotheses were generally supported. We anticipated that auditory processing would play an important role in children's reading acquisition skills. Children between the ages of 6 and 9 years with average reading ability and auditory processing strengths (Cluster 5) were found to perform better on all four reading outcomes than children with profiles defined only by average reading ability with no notable auditory processing strengths (Cluster 1). Children at the extremes of the age continuum being considered (i.e., 5- and 10-year-old children) who had auditory processing strengths performed better than children without these strengths on three of the four reading outcomes.

We also expected that crystallized ability and short-term memory would become a contributing factor to reading success following ages 5 and 6. This hypothesis was partially supported, in that children of average reading ability with strengths in these areas (Cluster 3) actually began showing better performance on reading outcomes (i.e., Letter–Word Identification and Picture Completion) at age 6 in comparison to children with average reading ability profiles (Cluster 1). Differences between children comprising these two profiles were

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also observed at age 7 on a measure of Reading Vocabulary; however, at ages 8 and 10, children in Cluster 3 performed better than children in Cluster 1 on all four reading outcomes. Nine-year-old children in Cluster 3 also performed better than children in Cluster 1 on three of the four reading outcomes.

Finally, we anticipated that processing speed would be an important predictor of reading success in the early years. Children with average reading ability and processing speed strengths (Cluster 6) were found to perform better than children in Cluster 1 on all four reading outcomes at ages 6, 7, and 9. Cluster 6 children also outperformed children in Cluster 1 on three reading outcomes at age 8 and two reading outcomes at age 10.

DISCUSSION

The Simple View of reading proposes a model that has guided much research on reading acquisition. Studies have been conducted to identify cognitive processes that are involved in the two primary components of reading, defined by the Simple View as decoding and listening comprehension. Such inquiries have revealed several important predictors of reading ability, including orthographic knowledge, phonemic awareness, and oral vocabulary (Adams, 1990; Juel, 1994; Snow et al., 1998; Wagner et al., 1994). These investigations provide the foundation for better understanding the needs of emergent readers. However, a complete understanding of the complex processes of learning to read requires investigations that consider the full network of relationships among these processes and their joint impact on reading outcomes. Within the Gf–Gc framework, multivariate research reveals that auditory processing/phonological awareness, crystallized ability, processing speed, and short-term memory all contribute to success in basic reading and acquiring reading comprehension skills (McGrew, 1994).

Much of the empirical research on reading acquisition is grounded in procedures that examine relationships among variables (e.g., correlation, multiple regression), with little emphasis on how children's score *patterns* on these variables influence their ability to become successful readers. The current study explicitly addressed the reading ability patterns that are likely to be found among heterogeneous groups by identifying homogeneous score configurations based on children's patterns of strengths and weaknesses. The educational utility of these groupings comes by way of identifying profiles that are predictive of successful readers. In other words, what strengths are important to reading acquisition? This issue was addressed by comparing children with similar score configurations (i.e., profiles) to children with different profiles on various reading outcomes.

Six core profiles were empirically identified, within a large nationally standardized sample, on measures of four Gf–Gc constructs previously found to be both theoretically and empirically linked to children's reading acquisition. These profiles are typical of what we would expect to observe and represent the most common score configurations among children between the ages of 5 and 10 years. This latter claim is supported by the fact that each profile was comprised of proportionately equal numbers of children from each of the six age groups.

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The internal and external validity of these profiles was very favorable, suggesting homogeneous within-cluster membership and clear separation among the six core profiles. In addition, the six-cluster solution was supported through cross-validation.

Profiles were defined in terms of patterns of strengths and weakness across measures of the four Gf–Gc constructs under consideration. Three of the profiles were relatively flat. These flat profiles were unremarkable in terms of strengths or weaknesses and were defined by varying degrees of general reading ability. The remaining three profiles were defined primarily by average reading ability with secondary strengths in auditory processing, processing speed, and crystallized ability and short-term memory.

Comparisons between children comprising different profiles, on four measures of basic reading skills and reading comprehension, revealed that certain profiles were associated with greater success on external measures of reading achievement than others. Not surprisingly, children in Cluster 4, defined solely by above average ability, generally performed better on all four reading outcomes than children with any other profile type. Conversely, children in Cluster 2, defined solely by below-average ability, failed to outperform children with other profile types on any of the four reading outcomes. This finding held across children ranging in age from 5 to 10 years.

The more interesting findings come by way of comparison between profiles defined by average ability and by average ability with notable Gf–Gc strengths. First, children of average ability with auditory processing/phonological awareness strengths (Profile 5) were more successful on all four reading outcome measures than children of average ability with no secondary strengths (Profile 1). This trend was apparent across the entire range of ages under investigation (i.e., 5–10 years of age). At age 5, these children also performed better than children with processing speed or crystallized ability and short-term memory strengths on Word Attack than children with crystallized ability and short-term strengths on Reading Vocabulary. Second, children of average ability with processing speed strengths (Profile 6) were more successful than children of average ability with no secondary strengths on both measures of basic reading skills and one measure of reading comprehension (i.e., Passage Comprehension) at age 6. Children 7–9 years of age with this profile were more successful on all reading outcome measures, with one exception occurring at age 8 on Word Attack. At age 7, these children performed better than children with crystallized ability and short-term memory strengths on both basic reading skill measures. At age 10, children with secondary processing speed strengths only performed better than children of average ability with no secondary strengths on reading comprehension tasks (i.e., Reading Vocabulary and Passage Comprehension). Third, children with crystallized ability and short-term memory strengths (Profile 3) began demonstrating gains over children of average ability with no secondary strengths at age 6. These gains became most pronounced at age 8 and continued through age 10. At ages 8 and 10, children with this profile type also performed better than children with auditory processing/phonological awareness or processing speed strengths on Reading Vocabulary.

The current analysis indicates that in reading development, oral vocabulary

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and listening comprehension, comprising half the equation in the Simple View of Reading, need to be considered jointly with working memory (i.e., Profile 3). Furthermore, whereas phonological awareness (which is intricately tied to decoding, the other half of the Simple View equation) and processing speed independently surfaced as strengths for different groups of children with average reading ability (Profiles 5 and 6, respectively), the strength of the contribution of each was somewhat parallel (i.e., at ages 6 and 9, children with strengths in either phonological awareness or processing speed outperformed those with no secondary strengths or those with secondary strengths in either comprehension or short-term memory). The coincidence of strengths in these cognitive variables, at the same ages in development, suggests that, not only does phonological awareness need to be regarded as affecting reading ability (as in the Simple View of Reading), but processing speed must also be considered as an important cognitive mediator. Furthermore, children with above-average reading ability profiles (Profile 4) showed strengths in all the achievement measures, suggesting that when all these cognitive abilities function in concert at a high level, the most desirable reading outcomes are achieved.

The data in this study also suggest that the importance of certain cognitive variables is mediated by the age of the child. Strengths in phonological awareness seem to outweigh other strengths at age 5 in influencing reading skills. Phonological awareness and processing speed both seem to facilitate better reading at ages 6 through 9 (although processing speed did not surface as an important strength at age 8). Strengths in crystallized ability (comprehension knowledge) and short-term memory, however, demonstrated greater importance for distinguishing readers than other cognitive measures for 10-year-old children.

The Simple View of Reading is a useful framework for conceptualizing the components of reading ability. This model proposes that reading ability is the product of decoding and listening comprehension. However, a closer look at the relationship between the individual cognitive components involved in decoding (auditory processing/phonological awareness), listening comprehension (crystallized ability), and other cognitive mediators (short-term memory and processing speed) provides a more detailed view of the complex nature of the cognitive functions active in reading acquisition.

The results described above provide information regarding the multivariate nature of children's reading ability patterns and their influence on various reading outcome measures. These results are suggestive of a compensatory hypothesis, one that acknowledges that there is more than one route to successful, or at least adequate, reading performance among predominately average ability children. The findings provide insight into the difficulties children are likely to face in learning to read when they do not possess the necessary foundation. This tool, in contrast to earlier ones, allows us to get inside "achievement" to learn more about the particular pathways, as indexed by profiles of skill strengths and weaknesses, that distinct groups of readers follow in arriving at particular levels of overall achievement or performance. Knight and Fischer (1992) proposed that it is possible to distinguish different, yet typical, pathways of development in reading. They stated, "A child's profile can be used to determine which of several sequences he or she is developing through" (p. 381). We believe we

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have identified some typical profiles. The task now is to refine our models and understand how children with different profiles can best be assisted through instruction. This approach has the additional virtue of teaching us, as scholars and theorists, something about the nature of reading development in these critical early years.

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