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GENERAL ARTICLES

The Relations Between Measures of Cattell-Horn-Carroll (CHC) Cognitive Abilities and Reading Achievement During Childhood and Adolescence

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Abstract. This study examined the relations between the Cattell-Horn-Carroll (CHC) theory of cognitive abilities and reading achievement during childhood and adolescence. In a large, nationally representative sample including students 6 to 19 years of age, operational measures of CHC cognitive abilities obtained from the Woodcock-Johnson III (WJ III; Woodcock, McGrew, & Mather, 2001) were found to be significantly related to the components of reading achievement. Multiple regression analyses were used to regress several WJ III cognitive clusters onto the WJ III Basic Reading Skills and Reading Comprehension clusters for 14 age groups. Comprehension-Knowledge (*Gc*) demonstrated moderate to strong relations with the components of reading achievement across childhood and adolescence, and Short-term Memory (*Gsm*) demonstrated moderate relations throughout this period. Auditory Processing (*Ga*), Long-term Retrieval (*Glr*), and Processing Speed (*Gs*) demonstrated moderate relations with the components of reading achievement during the elementary school years. More specialized cognitive clusters (viz., Phonemic Awareness and Working Memory) demonstrated moderate to strong relations. In contrast, Fluid Reasoning (*Gf*) and Visual-Spatial Thinking (*Gv*) demonstrated no consistent pattern of significant relations across childhood and adolescence. The results offer external validity evidence for the WJ III cognitive clusters and provide valuable insights into the specific cognitive abilities that are important for understanding the development of reading skills during childhood and adolescence.

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Ideally, all children would come to reading instruction with the prerequisite abilities. Unfortunately, some children display weaknesses or deficits in core cognitive abilities and experience significant problems in the acquisition of reading skills. Recently, the National Research Council's Committee on the Prevention of Reading Difficulties in Young Children integrated the available literature on reading skill development and reading disabilities in *Preventing Reading Difficulties in Young Children* (Snow, Burns, & Griffin, 1998). This report identified a variety of child-based risk factors for reading failure, such as developmental delay in general cognitive development, hearing impairment, early language impairment, and attention deficits. In the cognitive and language domains, a variety of abilities were mentioned as pivotal to reading development. These included linguistic proficiency, verbal memory, lexical and syntactic skills, general language abilities, and phonological awareness. It is clear that success (or failure) in reading is a multivariate process.

According to Snow et al. (1998), practice and research in the field of reading have not been particularly coherent and systematic. In clinics and schools, the assessment of reading is often characterized by a diverse array of instruments that may be redundant and incomplete with respect to the necessary range of knowledge and abilities necessary for proficient reading. Reading researchers have also used differing sets of predictor measures across studies and have frequently failed to include some of the most important predictors of reading in their investigations. The omission of potentially important variables in predictive or explanatory research is considered a form of *specification error*, a type of modeling error that can lead to biased estimates of the effects of predictive variables. Specification error during reading research is especially problematic because (a) cognitive abilities that are excluded from analyses may be judged to be unimportant when they are vital; (b) the relative contribution of a number of abilities to reading achievement remains unknown; (c) researchers may continue to build on studies that were limited in the abilities that were assessed, which may lead to premature reliance on certain predictor measures; and (d) possibly most important, consumers of this research may be misled into omitting important predictive measures from their assessments. One of the most effective means to avoid specification error is to use formal, well-validated models about the phenomena of interest to guide the selection of measures that should be included in analyses (Licht, 1995).

Cattell-Horn-Carroll Theory of Cognitive Abilities

The Cattell-Horn-Carroll (CHC) theory of cognitive abilities is considered to be one of the most well-validated models of cognitive abilities (Flanagan & Ortiz, 2001; McGrew & Flanagan, 1998; Woodcock, McGrew, & Mather, 2001). CHC theory is grounded in more than half a century of factor analytic research, and developmental studies of cognitive abilities, genetic heritability research, and neurocognitive analyses have contributed to its validity base (see Horn & Noll, 1997). The theory is a recent synthesis of the Cattell-Horn *Gf-Gc* theory (Horn & Noll, 1997) and the Carroll three-stratum theory of cognitive abilities (Carroll, 1993, 1997). CHC theory is a hierarchical framework of human cognitive abilities that consists of three strata: general intelligence or *g* (stratum III), broad cognitive abilities (stratum II), and narrow cognitive abilities (stratum I). The broad cognitive abilities include Fluid Reasoning (*Gf*), Comprehension-Knowledge (*Gc*), Short-term Memory (*Gsm*), Visual Processing (*Gv*), Auditory Processing (*Ga*), Long-term Retrieval (*Glr*), Processing Speed (*Gs*), Reading and Writing (*Grw*), Quantitative Knowledge (*Gq*), and Decision/Reaction Time or Speed (*Gt*). Approximately 70 narrow cognitive abilities are subsumed by these broad abilities (McGrew & Flanagan, 1998). The recognition of CHC theory as a well-validated conceptualization of cognitive abilities begs for its interjection as a potentially useful organizing framework for research on typical and atypical reading skill development.

CHC-Organized Reading Research

A number of studies have examined the validity of CHC measures in predicting reading achievement.[1] McGrew (1993) examined the relations between the seven Woodcock-Johnson Psycho-Educational Battery—Revised (WJ-R; Woodcock & Johnson, 1989) *Gf-Gc* cognitive clusters and the WJ-R Basic Reading Skills and Reading Comprehension clusters across the lifespan. Multiple regression analyses of data from the WJ-R standardization sample indicated that Comprehension-Knowledge (*Gc*) demonstrated the strongest relations with the reading clusters at almost all age levels. Short-term Memory (*Gsm*) displayed moderate relations with both reading clusters from the earliest ages through middle adulthood. Auditory Processing (*Ga*) and Processing Speed (*Gs*) were consistently and significantly related to Basic Reading Skills until early adulthood; however, the strength of the relations between these clusters and Reading Comprehension declined notably after the elementary school years. Fluid Reasoning (*Gf*) was significantly associated with Reading Comprehension between ages 5 and 30, but it was largely unrelated to Basic Reading Skills. Finally, Long-term Retrieval (*Glr*) and Visual-Spatial Thinking[2] (*Gv*) demonstrated no significant relations with either reading cluster.

Similar findings have surfaced from structural equation modeling (SEM) analyses of data from the WJ-R standardization sample and from independent samples using the WJ-R cognitive clusters and the Wechsler scales (Wechsler, 1974, 1991). After using SEM to account for the effects of *g* in the analysis, McGrew, Flanagan, Keith, and Vanderwood (1997) and Keith (1999) demonstrated significant relations between Auditory Processing (*Ga*) and Comprehension-Knowledge (*Gc*) and reading achievement in a group of school-age children included in the WJ-R standardization sample. Using multiple regression procedures, Williams, McCallum, and Reed (1996) demonstrated the power of *Gc* and Processing Speed (*Gs*) in predicting reading achievement measured by the California Test of Basic Skills-4 (Macmillan/McGraw-Hill, 1989) in a group of school-age children. More recently, regression analyses conducted by Garcia and Stafford (2000) indicated that *Ga* and *Gc* were significant predictors of reading achievement in a sample of first and second grade students from low-income families. SEM analysis of select Wechsler Intelligence Scale for Children, Revised (Wechsler, 1974) composites supplemented with WJ-R *Gf-Gc* cognitive clusters by Flanagan (2000) also revealed that, after specifying the effects of *g*, *Gc* and *Gs* demonstrated large and moderate direct effects, respectively, for reading comprehension. *Ga* abilities demonstrated strong direct effects for basic reading skills. Finally, Hale, Fiorello, Kavanagh, Hoeppner, and Gaither (2001) reported that when CHC-organized commonality analyses were applied to the Wechsler Intelligence Scale for Children, Third Edition (Wechsler, 1991) Full Scale IQ and factor indexes, significant relations between Short-term Memory (*Gsm*), Quantitative Knowledge (*Gq*), and *Gc* and reading achievement were present above and beyond those associated with the Full Scale IQ.

Purpose of Current Study

These studies provide evidence of the external validity of specific CHC abilities in predicting reading achievement, even when the effects of *g* are included in the analyses. However, at present, there is a need to expand the understanding of the cognitive predictors of reading achievement using more recently developed measures of CHC abilities that ensure better construct validity via increased construct representation (see Flanagan et al., 2000; Flanagan & Ortiz, 2001; McGrew & Woodcock, 2001). Because the WJ III Tests of Cognitive Abilities (COG; McGrew & Woodcock, 2001) was designed to provide greater construct representation in the measurement of CHC cognitive abilities, it offers a sound research instrument to examine these relations. As a first step in examining the relations between CHC cognitive abilities and reading achievement, this study used multiple regression analyses to investigate the validity of the WJ III COG cognitive clusters in predicting basic reading skills and reading comprehension during childhood and adolescence. Investigating the relations between the specific CHC broad (stratum II) and narrow (stratum I) cognitive abilities and reading achievement, vis-à-vis the WJ III COG measures, may influence future research examining the cognitive predictors of reading abilities and contribute to improved diagnosis, identification, and remediation of reading deficits during the school-age years.

Method

Participants

All participants were drawn from the nationally representative standardization sample of the WJ III, which included 8,818 individuals ranging in age from 24 months to more than 95 years of age (Woodcock et al., 2001). Standardization participants between 6 and 19 years of age were included in the current analyses if they completed the tests that form the Basic Reading Skills and Reading Comprehension clusters of the WJ III Tests of Achievement (ACH; Woodcock & Mather, 2001). Thus, two subsamples from the larger standardization sample were formed ($n = 4,338$ for Basic Reading Skills and $n = 3,303$ for Reading Comprehension).

To determine the representativeness of the two subsamples used in these analyses, select demographic variables were examined. Each WJ III norming participant was assigned a unique weight that represented each participant's required contribution to the final norms as per the United States Census statistics used during norming (see McGrew & Woodcock, 2001). A comparison of weighted and unweighted descriptive statistics for gender, for racial group (i.e., White, Black, American Indian, and Asian and Pacific Islander), and for *W*-scores for the two reading clusters suggested that the two subsamples included in this study were largely similar to the United States population of 6- to 19-year-olds.[3]

Measures

Reading clusters. This study used the Basic Reading Skills and Reading Comprehension clusters from the WJ III ACH (Woodcock & Mather, 2001) to represent reading decoding and reading comprehension skills (see Table 1). Correlations between these clusters and reading clusters from the Kaufman Test of Educational Achievement (Kaufman & Kaufman, 1985) and the Wechsler Individual Achievement Test (Wechsler, 1992) provide evidence supporting their validity. Correlations ranged from .66 to .82 in a sample of first- to eighth-grade children (McGrew & Woodcock, 2001). Furthermore, validity evidence has been provided for the identically comprised reading clusters from the WJ-R (McGrew, Werder, & Woodcock, 1991) and the Woodcock-Johnson Psycho-Educational Battery (Woodcock, 1978).

Cognitive clusters. This study used the seven CHC factor clusters from the WJ III COG to represent the CHC broad (or stratum II) cognitive abilities. Two tests comprise each of the seven CHC factor clusters (see Table 1). This study also used two WJ III COG clinical clusters and another clinical cluster formed by tests from both batteries. These clinical clusters operationalize abilities (i.e., phonemic awareness and working memory) reported to be important predictors of reading achievement (Snow et al., 1998). Two tests comprise the Phonemic Awareness cluster and the Working Memory cluster, and two tests from the WJ III COG and one test from the WJ III ACH comprise the Phonemic Awareness-3 cluster (see Table 1). The three clinical clusters represent narrow (or stratum I) cognitive abilities. The Phonemic Awareness and Phonemic Awareness-3 clusters operationalize the narrow cognitive ability Phonetic Coding, which is subsumed by Auditory Processing (*Ga*). The Working Memory cluster operationalizes the narrow cognitive ability of the same name, which is subsumed by Short-term Memory (*Gsm*). Reliability and validity evidence for the CHC factor clusters and clinical clusters is presented in McGrew and Woodcock (2001).

Analysis

The two subsamples were divided into 14 different age-based groups, each represent-

Table 1
Descriptions of WJ III Reading Clusters and Cognitive Clusters

WJ III Cluster	Description of Cluster	Type of Cluster	Tests Forming Cluster
Tests of Achievement			
Basic Reading Skills	Ability to identify individual printed letters and words and to pronounce phonically regular nonsense words	Achievement Cluster	Letter-Word Identification Word Attack
Reading Comprehension	Ability to read words and understand written text, produce appropriate synonyms and antonyms, and complete analogies	Achievement Cluster	Passage Comprehension Reading Vocabulary
Tests of Cognitive Abilities			
Comprehension-Knowledge (*Gc*)	Ability to use language and acquired knowledge effectively	CHC Factor Cluster	Verbal Comprehension General Information
Long-term Retrieval (*Glr*)	Ability to store and readily retrieve information in long-term memory	CHC Factor Cluster	Visual-Auditory Learning Retrieval Fluency
Visual-Spatial Thinking (*Gv*)	Ability to recognize spatial relationships and to analyze and manipulate visual stimuli	CHC Factor Cluster	Spatial Relations Picture Recognition
Auditory Processing (*Ga*)	Ability to perceive, attend to, and analyze patterns of sound and speech that may be presented in distorted conditions	CHC Factor Cluster	Sound Blending Auditory Attention
Fluid Reasoning (*Gf*)	Ability to form and recognize logical relationships among patterns, and to make deductive and inductive inferences, and to transform novel stimuli	CHC Factor Cluster	Concept Formation Analysis-Synthesis
Processing Speed (*Gs*)	Ability to perform simple cognitive tasks quickly, especially when underpressure to maintain focused attention and concentration	CHC Factor Cluster	Visual Matching Decision Speed
Short-term Memory (*Gsm*)	Ability to understand and store information in immediate awareness and then use it within a few seconds	CHC Factor Cluster	Numbers Reversed Memory for Words
Phonemic Awareness	Ability to perceive separate units of speech sounds in order to analyze and synthesize those units	Clinical Cluster	Sound Blending Incomplete Words

Table 1 continues

Table 1 continued

WJ III Cluster	Description of Cluster	Type of Cluster	Tests Forming Cluster
Working Memory	Ability to temporarily store and mentally manipulate information held in immediate memory	Clinical Cluster	Numbers Reversed Auditory Working Memory
Phonemic Awareness-3	Ability to perceive and manipulate units of speech	Clinical Cluster	Sound Blending Incomplete Words Sound Awareness

ing 1 year of age starting at age 6 and continuing through age 19.[4] The WJ III *W*-score was the metric of analysis. *W*-scores are transformations of raw scores into equal interval units that are derived through application of the 1-parameter item response theory or Rasch measurement model (Woodcock, 1978; Woodcock & Dahl, 1971). The *W*-score of each test is centered on a value of 500, which is the approximate average performance of a 10-year-old child. Each cluster *W*-score represents the arithmetic average of the *W*-scores of the tests comprising the cluster.

For each WJ III cognitive cluster and each reading achievement cluster, 14 standardized regression coefficients were plotted on a graph with age representing the x-axis. Standardized regression coefficients indicate the proportion of standard deviation units that the criterion variable changes as a function of one standard deviation change in a predictor variable. For example, a WJ III Comprehension-Knowledge (*Gc*) standardized regression coefficient of .25 with the WJ III Basic Reading Skills cluster means that for every standard deviation change observed in *Gc* scores, there is an average of .25 standard deviation change in Basic Reading Skills scores. Given that sampling error is present to an unknown degree in each age-differentiated sample, the best population estimates of the age-related changes between the cognitive cluster and the achievement domain were identified through the application of the distance-weighted least squares smoothing function to the plot of the standardized regression coefficients (Wilkinson, 1990; see McGrew & Wrightson, 1997).

For the initial regression analyses, the predictor variables were the seven CHC factor clusters. In one model, the criterion measure was the Basic Reading Skills cluster, whereas in the other model, the criterion was the Reading Comprehension cluster. Two additional regression analyses were completed to investigate the relations between the three clinical clusters and the two reading achievement clusters. In the second regression analysis, the Phonemic Awareness and Working Memory clusters were substituted for the Auditory Processing (*Ga*) and Short-term Memory (*Gsm*) clusters, respectively. In the third analysis, only the Phonemic Awareness-3 cluster was substituted for the *Ga* cluster.

Results

Results of the analysis are presented in Figures 1 through 5.[5] Each figure displays four lines representing the smoothed standardized regression coefficients for two cognitive clusters that were used as predictors of Basic Reading Skills and Reading Comprehension. Each graph includes two parallel dashed lines that correspond to standardized regression coefficients of .10 and .30. The lines are guides for interpreting the significance of the smoothed regression coefficient values and correspond to previously established rules-of-thumb (McGrew, 1993; McGrew & Hessler, 1995; McGrew & Knopik, 1993). These rules operationally define practical significance to be associated with standardized regression coefficients of .10 or above. Coefficients ranging from .10 to .29 are classified as representing *moderate* effects, whereas those .30 or above are classified as *strong* effects.[6]

CHC Factor Clusters

Standardized regression coefficients reveal differential relations between the WJ III cognitive clusters and reading achievement across childhood and adolescence. Two CHC factor clusters, Comprehension-Knowledge (*Gc*) and Short-term Memory (*Gsm*), were significantly and consistently related to at least one of the reading clusters (see Figure 1). The *Gc* cluster demonstrated the strongest and most consistent relations with both Basic Reading Skills and Reading Comprehension. It demonstrated moderate and strong relations with both reading clusters that increased monotonically from age 6 through much of adolescence. The Short-term Memory (*Gsm*) cluster displayed consistent moderate relations with Basic Reading Skills. However, its relations with Reading Comprehension were notably lower in magnitude throughout the entire period of the analysis.

Three CHC factor clusters, Auditory Processing (*Ga*), Long-term Retrieval (*Glr*), and Processing Speed (*Gs*), demonstrated consistent patterns of significant relations with Basic Reading Skills and Reading Comprehension only during the formative years of reading skill acquisition. Relations between *Ga* and Basic Reading Skills and Reading Comprehension were moderate in magnitude from ages 6 to 9 (see Figure 2). *Glr* demonstrated moderate effects with Basic Reading Skills from ages 6 through 9 and with Reading Comprehension from ages 6 through 11 (see Figure 2). *Gs* demonstrated moderate effects with both Basic Reading Skills and Reading Comprehension from age 6 to approximately age 10 (see Figure 3).

Two CHC factor clusters demonstrated no pattern of significant relations with the reading clusters. The smoothed curves for Fluid Reasoning (*Gf*) demonstrated no consistent pattern of significant effects with Basic Reading Skills and Reading Comprehension (see Figure 3). Exceptions to this pattern surfaced in the Reading Comprehension model between the ages of 11 to 14. Given that these significant effects were present only for a few age levels and that they were in the context of nonsignificant effects at all other age levels, these effects may be best interpreted as reflecting sampling error. Visual-Spatial Thinking (*Gv*) also demonstrated no consistent pattern of significant effects with the reading clusters (see Figure 4). The slight upward trend towards significance for *Gv* at ages 18 and 19 can be interpreted as reflecting sampling error.

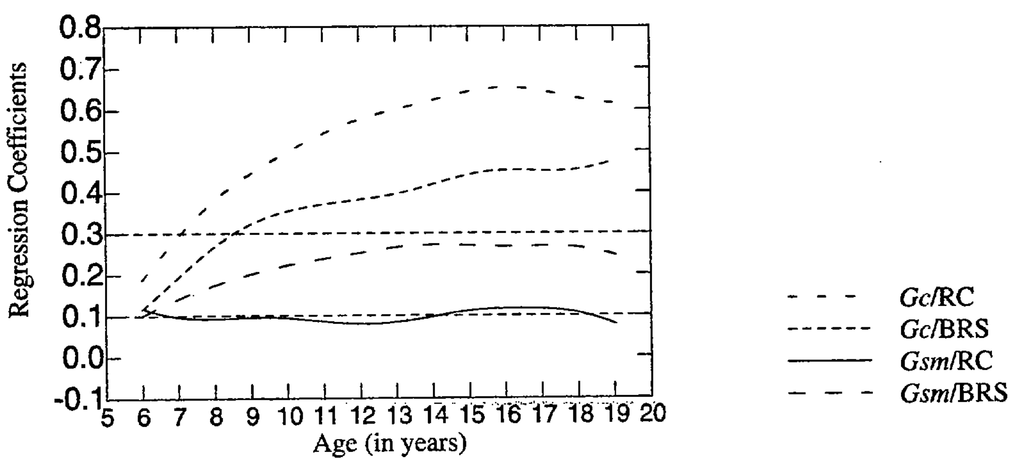

Figure 1. Standardized regression coefficients as a function of age for Comprehension-Knowledge (*Gc*) and for Short-Term Memory (*Gsm*) with Basic Reading Skills (BRS) and Reading Comprehension (RC).

Clinical Clusters

The results from the second set of regression analyses, in which the clinical clusters Phonemic Awareness and Working Memory were substituted for the Auditory Processing (*Ga*) and Short-term Memory (*Gsm*) clusters, revealed patterns of relations with Basic Reading Skills and Reading Comprehension that were similar to those of the broad cognitive abilities. Like *Ga*, Phonemic Awareness demonstrated moderate relations with the reading clusters primarily during the early elementary school years (see Figure 4). In the same analysis, Working Memory displayed consistent moderate relations with Basic Reading Skills, in a manner similar to *Gsm* (see Figures 1 and 5). In slight contrast to the *Gsm* analysis, the relations between Working Memory and Reading Comprehension peaked at age 6 but remained moderate from ages 7 to approximately age 16.

In the third set of regression analyses, in which clinical cluster Phonemic Awareness-3 was substituted for the Auditory Processing (*Ga*) cluster, Phonemic Awareness-3 demonstrated significant and consistent relations with Basic Reading Skills (see Figure 5). Phonemic Awareness-3 demonstrated strong relations with Basic Reading Skills from ages 6 through 8 and continued to demonstrate moderate relations with Basic Reading Skills throughout the school-age years. The relations between Phonemic Awareness-3 and Reading Comprehension were significant during the span of ages 6 through 9 and again during the span of ages 14 through 19. However, the smoothed curve between the ages of 9 and 14 indicated nonsignificant relations with Reading Comprehension.

Discussion

When integrated with prior CHC-organized research, this study contributes to an emerging body of theory-based knowledge regarding the potentially important relations between CHC cognitive abilities and reading achievement. Research building on this knowledge minimizes the degradation of reading research findings that can occur because of failure to include measures of important cognitive or psycholinguistic constructs (i.e., specification error) in research studies (Snow et al., 1998). In this context, these results have notable implications for reading research and practice.

Comprehension-Knowledge and Reading

A large body of research literature has established a strong link between verbal ability, semantic or lexical processing, or general

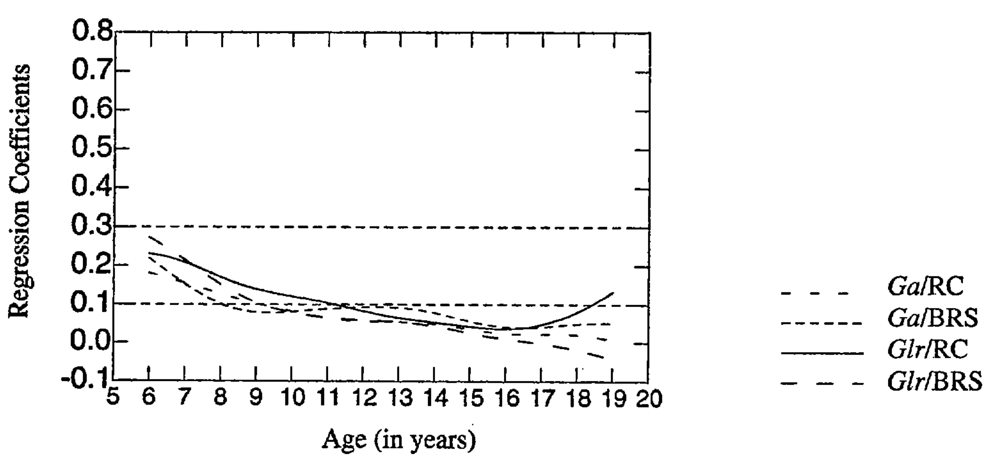

Figure 2. Standardized regression coefficients as a function of age for Auditory Processing (*Ga*) and for Long-Term Retrieval (*Glr*) with Basic Reading Skills (BRS) and Reading Comprehension (RC).

language development and reading achievement (e.g., Dufva, Niemi, & Voeten, 2001; Garcia & Stafford, 2000; Goswami, 2000; Vellutino, Scanlon, & Lyon, 2000; Williams et al., 1996). Thus, it was not surprising that the Comprehension-Knowledge (*Gc*) cluster was generally the strongest predictor of Basic Reading Skills and Reading Comprehension in these analyses (see Figure 1). The relations between reading achievement and the breadth and depth of a person's knowledge are logical. Both abilities stem largely from the acquisition of declarative and procedural knowledge (Woodcock, 1993, 1998) and, in fact, may be considered types of academic achievement (Anastasi, 1988; Flanagan et al., 2002; Kaufman, 1994; Woodcock, 1990). Additionally, Carroll's (1993) analysis and review of human cognitive abilities included both reading and writing abilities under the second stratum ability *Crystallized Intelligence*. It is clear that the link between *Gc* and reading achievement is robust and increasing as a function of age. This link may reflect a bidirectional relationship, whereas vocabulary and general knowledge contribute to reading abilities and vice versa (Stanovich, 1986). This hypothesis may explain the notable increase in the predictive power of *Gc* abilities after age 8 (see Figure 1). Thus, these cognitive abilities may be less important for early reading acquisition than other CHC cognitive abilities, such as Long-term Retrieval (*Glr*) and Phonetic Coding (e.g., Vellutino et al., 1996); however, the bidirectional relations appear to become stronger once basic reading skills are established.

Short-Term Memory, Working Memory, and Reading

Relations between Short-term Memory (*Gsm*) and Working Memory and the reading clusters in this study demonstrate both discrepancies and consistencies with prior reading research. Research that has included both (a) measures of the CHC narrow (or stratum I) cognitive abilities of Memory Span—the ability to attend to and immediately recall elements (without clear semantic relationships) in the correct order after a single presentation—and (b) measures of Working Memory—the ability to temporarily store and perform cognitive operations on information that requires divided attention and the management of the limited capacity of immediate memory—has typically found Working Memory to be more strongly related to reading performance than Memory Span (Dufva et al., 2001; Kail & Hall, 2001). In this study, the *Gsm* cluster includes measures of Working Memory and Memory Span, and the Working Memory cluster includes two

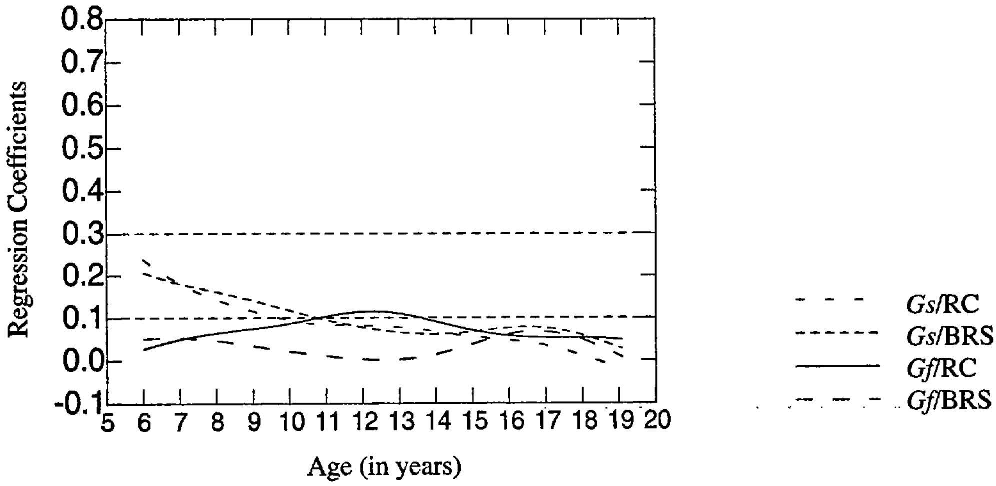

Figure 3. Standardized regression coefficients as a function of age for Processing Speed (*Gs*) and for Fluid Reasoning (*Gf*) with Basic Reading Skills (BRS) and Reading Comprehension (RC).

measures of Working Memory. The smoothed coefficients for two clusters indicate similar patterns of moderate relations with Basic Reading Skills (see Figures 1 and 5). Prior research would have predicted a lower degree of association for the mixed *Gsm* cluster than that for the Working Memory cluster (Dufva et al., 2001; Kail & Hall, 2001; Oakhill, Yuill, & Parkin, 1986; Stothard & Hulme, 1992).

In contrast to the Basic Reading Skills analysis, the moderate relations between Working Memory and Reading Comprehension from ages 6 through most of adolescence (see Figure 5) and the lack of relations of the same magnitude for *Gsm* during the early school-age years demonstrate consistencies with prior research. The relations between Working Memory and Reading Comprehension corroborate research findings that suggest that, during the process of reading, working memory space may provide a holding area for the analysis of language-based stimuli that cannot occur concurrently with the decoding of words (Dufva et al., 2001). The age-related, slightly decreasing trend in the relations between Working Memory and Reading Comprehension from ages 6 through midadolescence also supports recent research findings and hypotheses. The downward trend may be consistent with the hypothesis that as children increase in age, their reading processes become more automatized and require less use of working memory (Dufva et al., 2001). Also, the developmental cascade hypothesis suggests that both working memory and speed of mental processing increase in capacity with increasing age (viz., maturation). These developments, in turn, mediate more efficient functioning during complex cognitive tasks, such as reading comprehension (Fry & Hale, 2001). As a result, working memory may decrease in importance during reading comprehension as maturing children approach their working memory space capacity.

Auditory Processing and Reading

Probably the most well-publicized finding in the reading disability research during the past decade is the pivotal role that specific auditory abilities (viz., phonological or phonemic awareness and speech perception) play in early reading skill development and reading failure (Blachman, 2000; McBride-Chang, 1996; Morris et al., 1998; Snow et al., 1998; Stanovich, Siegel, & Gottardo, 1997; Torgeson, Wagner, Rashotte, Burgess, & Hecht, 1997; Wagner et al., 1997). The moderate relations for Auditory Processing (*Ga*; see Figure 2) and for Phonemic Awareness (see Figure 4) with Basic Reading Skills that appear primarily

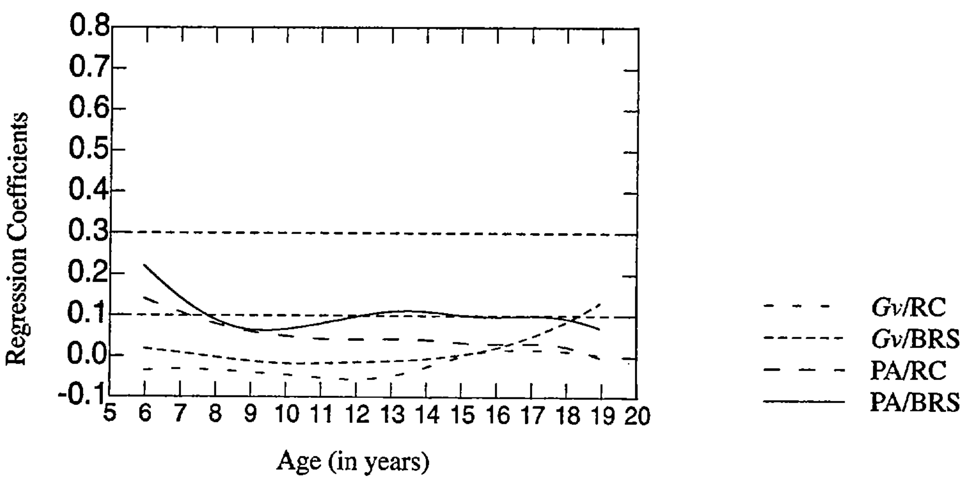

Figure 4. Standardized regression coefficients as a function of age for Visual-Spatial Thinking (Gv) and for Phonemic Awareness (PA) with Basic Reading Skills (BRS) and Reading Comprehension (RC).

from age 6 to approximately age 9, coupled with slightly weaker relations with Reading Comprehension during the same age span, support this research demonstrating links between specific auditory abilities and *early* reading skill development (e.g., Goswami, 2000; Torgeson et al., 1997).

Perhaps the most exciting and unique contribution of this study was the increase in the magnitude of the prediction of Phonemic Awareness-3 (see Figure 5) beyond those of *Ga* and Phonemic Awareness. Not only did Phonemic Awareness-3 demonstrate strong relations with Basic Reading Skills from the ages of 6 to 8, but it also continued to demonstrate moderate relations with this reading cluster throughout the period of analysis. Furthermore, and possibly more surprising, was the finding that Phonemic Awareness-3 was a significant predictor of Reading Comprehension during the early school-age years and again in adolescence. The increased predictive power of this cluster may be explained by the following hypotheses. First, the subtests comprising Sound Awareness, which require phoneme manipulations such as deletions, reversals, and rhyming, are more complex than other phonemic awareness tasks (Stanovich, 1992). These tasks may tap specific phonological processing abilities, such as active phoneme manipulation, that are more predictive of reading achievement than onset-rime awareness or even phonetic analysis and synthesis abilities, per se, especially beyond the years of early reading skill acquisition. Second, performance on Sound Awareness may invoke a variety of controlled (versus automatic) processes involving the discrimination of sounds, the complex perception and manipulation of phonemes, and working memory (Kail & Hall, 2001). Third, the relations between this cluster and the reading clusters reflect reciprocal relationships between complex phoneme manipulation and literacy (Goswami & Bryant, 1990; Perfetti, Beck, Bell, & Hughes, 1987; Wagner, Torgeson, & Rashotte, 1994). Perhaps the most basic phonological processes exert a causal effect on early reading skills and the development of reading abilities advance more complex phonological processes, which in turn support reading skills across the lifespan (Blachman, 2000; Stahl & Murray, 1994).

Long-Term Retrieval and Reading

Long-term Retrieval (*Glr*) demonstrated moderate relations with both reading clusters during the early school-age years (see Figure 2). The tests that contribute to this cluster, Visual-Auditory Learning and Retrieval Fluency, and the narrow cognitive abilities they mea-

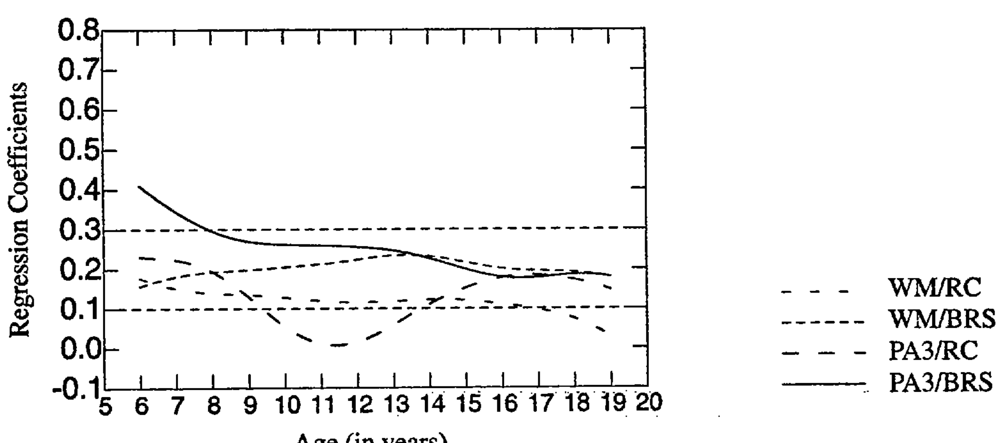

Figure 5. Standardized regression coefficients as a function of age for Working Memory (WM) and for Phonemic Awareness-3 (PA3) with Basic Reading Skills (BRS) and Reading Comprehension (RC).

sure provide some insight into its power to predict reading achievement. The test paradigm utilized in Visual-Auditory Learning requires learning and recalling words associated with symbols in a rebus-like format. These requirements are analogous to those of beginning reading (Vellutino et al., 1996). Because Visual-Auditory Learning is an actual learning task, it may reflect the extent to which individuals engage in rehearsal and memory searches for associations to help consolidate new material to be remembered. Recent research also has shown that Associative Memory, the CHC narrow cognitive ability that is typically measured by tests such as Visual-Auditory Learning, provides unique contributions to the prediction of reading achievement above and beyond phonemic awareness and short-term memory abilities (Windfuhr & Snowling, 2001).

The test paradigms of both Retrieval Fluency and Rapid Picture Naming, another WJ III COG test, require speeded retrieval of words. Retrieval Fluency requires examinees to name as many nouns from specified categories as they can in 1 minute, and Rapid Picture Naming requires examinees to label images of common objects rapidly. The similarity between these test paradigms is supported by SEM research indicating that these tests measure a factor subsumed by *Glr*, Naming Facility (McGrew & Woodcock, 2001). Substantial differences in the speed of producing names for common objects or attributes of objects define the CHC narrow cognitive ability Naming Facility (Carroll, 1993). The similarity between Carroll's definition and recent definitions and measurement tools for rapid automatic naming (RAN) is apparent. Significant relations between RAN and reading achievement have been highlighted during the past decade (Denckla & Cutting, 1999; Meyer, Wood, Hart, & Felton, 1998; Neuhaus, Foorman, Francis, & Carlson, 2001; Scarborough, 1998; Torgeson et al., 1997; Wolfe, Bowers, & Biddle, 2000). The moderate relations between the *Glr* cluster and early reading achievement suggest that other narrow memory storage and retrieval abilities, which are related to, but distinct from RAN, may also be important when learning to read. This conclusion is consistent with recent arguments that rapid naming ability may not be unitary but instead may be a factorially complex construct that requires the integration of a number of different abilities and processes (Neuhaus et al., 2001).

Processing Speed and Reading

Processing Speed (*Gs*) was moderately associated with both Basic Reading Skills and Reading Comprehension from approximately ages 6 to 10 years (see Figure 3). This finding is consistent with prior CHC-organized reading research (Flanagan, 2000; McGrew et al., 1997; Williams et al., 1996) and with a wide array of research that indicates that *Gs* is an important ingredient in the early stages of acquiring most cognitive or academic skills (Fry & Hale, 2001; Kail, 1991; Kail, Hall, & Caskey, 1999; Necka, 1999; Rasinski, 2000; Rindermann & Neubauer, 2000; Weiler et al., 2000). In general, it is hypothesized that the more rapidly and efficiently an individual can automatize basic academic or cognitive operations, the more attention and working memory resources can be allocated to higher level aspects of task performance. The previously described developmental cascade hypothesis explains that processing speed increases with maturation and exerts a direct and positive effect on working memory capacity. This greater capacity, in turn, mediates more efficient controlled functioning on complex cognitive and academic tasks, such as reading comprehension (Fry & Hale, 2001; Kail & Hall, 2001).

Fluid Reasoning and Reading

Although a number of studies have demonstrated that domain-specific problem-solving strategies (e.g., self-questioning) improve reading comprehension (see Aaron, 1997 and Mastropieri & Scruggs, 1997 for reviews), and it is logical that comprehension of written text relies upon reasoning abilities, few studies have examined the relations between Fluid Reasoning (*Gf*) abilities and reading achievement (cf. Santos, 1989). Previous analyses examining the predictive power of the WJ-R *Gf* cluster indicated that *Gf* abilities are significantly related with Reading Comprehension from the early school-age years to early adulthood (McGrew, 1993). However, the current results indicate that these novel reasoning abilities are not strongly related to either reading cluster (see Figure 3). Although the composition of the *Gf* cluster and the Reading Comprehension cluster is nearly identical in the WJ-R and WJ III, the finding of weaker relations between *Gf* and Reading Comprehension is most likely due to other cognitive clusters now accounting for more variance in prediction. Although the process of reading comprehension may draw upon reasoning abilities that are specific to the process of reading, the current study indicates that, within the context of all seven CHC factor clusters, *Gf* does not appear to add anything unique or significant to the prediction of reading achievement.

Visual-Spatial Thinking and Reading

Although some research exists to support the association between visual processing abilities (viz., visual memory and visual discrimination) and reading achievement in normative and reading-disabled populations (e.g., Eden, Stein, Wood, & Wood, 1996; Jackson, Donaldson, & Cleland, 1988; Kavale & Forness, 2000; Willows, Kruk, & Corcos, 1993), the prevailing conceptualization of the development of reading skills does not support the assertion that components of visual processing are strong predictors of these skills. Although perhaps visual processing abilities contribute to the earliest stages of reading acquisition (i.e., the logographic stage; de Jong & van der Leij, 1999), the results from the current study indicate consistently weak relations between Visual-Spatial Thinking (*Gv*) and reading achievement from age 6 through 19 years (see Figure 4). These results replicate the findings of the WJ-R reading regression study (McGrew, 1993). Although the WJ-R and WJ III Visual-Spatial Thinking (*Gv*) clusters contain Picture Recognition, a measure of Visual Memory, these findings are discrepant with several studies indicating the possible importance of short-term or immediate visual memory during the process of reading (e.g., Kavale & Forness, 2000). However, within the context of all seven CHC factor clusters, *Gv* does not appear to add anything unique or significant to the prediction of reading achievement.

Limitations

Several measurement and design limitations are notable. First, because this study relied on simultaneous multiple regression analyses in which all relevant cognitive variables were submitted as predictors, the resulting coefficients represent the incremental partitioning of the reading criterion variance. Thus, some cognitive abilities may be judged to be unimportant when analyzed concomitantly with other abilities that account for a greater proportion of the reading variance. Second, participants represent a random sample of children and adolescents. Therefore, these results may not generalize to children younger than age 6, to adults, or to children with learning disabilities or mental retardation.[7] Additional research including these samples is needed to support the application of these findings to these groups. Third, several predictor and criterion variables in this analysis may share latent abilities and be factorially complex. For example, Word Attack may measure both the CHC broad cognitive ability of Reading and Writing (*Grw*) and the narrow cognitive ability Phonetic Coding (McGrew, 1997; McGrew & Woodcock, 2001). Similarly, Reading Vocabulary and Passage Comprehension may measure both Reading and Writing (*Grw*) and abilities subsumed under Comprehension-Knowledge (*Gc*). Although these interrelations among measured abilities may represent causal relations (Keith, 1999; McGrew et al., 1997), the possible predictor/criterion contamination in this study may attenuate the predictive power of the respective cognitive clusters.

Summary

The current results support the phonological-core variable-difference model of reading disability (Morris et al., 1998; Stanovich, 1988; Stanovich & Siegel, 1994). This model asserts that the abilities of phonemic awareness, rapid naming, and the coding of phonological stimuli in short-term or phonological memory (i.e., the CHC narrow cognitive abilities Phonetic Coding, Naming Facility, and Memory Span or Working Memory, respectively) represent a cluster or module of abilities that enables reading skill development. Recent early reading intervention studies suggest that the children who begin schooling with normative deficits in these abilities are difficult to remediate with empirically validated intervention practices (see Vellutino et al., 2000). Although it is acknowledged that this model of reading disability recognizes that other cognitive ability deficits may co-occur with deficits in the phonological core and that these other abilities may influence reading development, the results of this study indicate that the focus on only the cognitive abilities associated with the phonological core is probably a premature restriction or specification (cf. Morris et al., 1998). It appears that these abilities in the phonological core interact with a number of other abilities that are strong predictors of reading achievement during childhood, such as Processing Speed (*Gs*) and Long-term Retrieval (*Glr*). Perhaps the children who are most resistant to intervention are also deficient in these cognitive abilities that typically are not specified in reading research. The current results indicate that the breadth of investigation of reading skill development and failure should be widened to include operational measures of these other abilities. We believe that organizing research investigations according to CHC theory would offer one remedy to specification error in current reading research.

Footnotes

[1]See McGrew and Flanagan (1998), Flanagan, McGrew, and Ortiz (2000), and Flanagan, Ortiz, Alfonso, and Mascolo (2002) for summaries of this research.

[2] The name for the *Gv* cluster on the WJ-R was Visual Processing. To increase readability, the WJ III cluster names are used when referring to the analogous WJ-R clusters.

[3]Due to space limitations, the specific results of these analyses are not reported. The analyses focusing on the representativeness of the samples and the specific statistics from the regression analyses can be obtained by contacting the authors or by visiting the website address http://www.iapsych.com/resrpts.htm.

[4] Due to space limitations, sample sizes for the 14 age-differentiated samples used in the regression models are not reported. These descriptive statistics can be obtained by (a) reviewing the descriptive statistics for Basic Reading Skills and Reading Comprehension cluster in the *WJ III Technical Manual* (McGrew & Woodcock, 2001), (b) contacting the authors, or (c) visiting http://www.iapsych.com/resrpts.htm.

[5] Graphs that include the smoothed curves and the raw regression coefficients for each cognitive ability can be obtained by visiting http://www.iapsych.com/resrpts.htm.

[6] These rules-of-thumb are generally similar to other rules-of-thumb for interpreting the effect sizes for manipulable influences on achievement or learning. According to Keith (1999), effect sizes that are less than .05 are not meaningful, effect sizes of .05 and above are *small* effects, effect sizes above .10 or .15 are *moderate* effects, and effect sizes above .25 are *large* effects.

[7]Because the WJ III standardization utilized a stratified random sampling plan, it is likely that children with learning disabilities, mental retardation, and other school-related problems were included in the samples.

References

Aaron, P. G. (1997). The impending demise of the discrepancy formula. *Review of Educational Research, 67*, 461-502.

Anastasi, A. (1988). *Psychological testing.* New York: Macmillan.

Blachman, B. A. (2000). Phonological awareness. In M. L. Kamil, P. B. Mosenthal, P. D. Pearson, & R. Barr (Eds.), *Handbook of reading research* (Vol. III, pp. 483-502). Mahwah, NJ: Lawrence Erlbaum Associates.

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor analytic studies.* New York: Cambridge University.

Carroll, J. B. (1997). The three-stratum theory of cognitive abilities. In D. P. Flanagan, J. L. Genshaft, & P. L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (pp. 122-130). New York: Guilford.

de Jong, P. F., & van der Leij, A. (1999). Specific contributions of phonological abilities to early reading acquisition: Results from a Dutch latent variable longitudinal study. *Journal of Educational Psychology, 91*, 450-476.

Denckla, M. B., & Cutting, L. E. (1999). History and significance of rapid automatized naming. *Annals of Dyslexia, 49*, 29-42.

Dufva, M., Niemi, P., & Voeten, M. J. M. (2001). The role of phonological memory, word recognition, and comprehension skills in reading development: From preschool to grade 2. *Reading and Writing, 14* (1-2), 91-117.

Eden, G. F., Stein, J. F., Wood, H. M., & Wood, F. B. (1996). Differences in visuospatial judgment in reading-disabled and normal children. *Perceptual and Motor Skills, 82*, 155- 177.

Flanagan, D. P. (2000). Wechsler-based CHC cross-battery assessment and reading achievement: Strengthening the validity of interpretations drawn from Wechsler test scores. *School Psychology Quarterly, 15*, 295-329.

Flanagan, D. P., McGrew, K. S., & Ortiz, S. O. (2000). *The WechslerIntelligence Scales and Gf-Gc theory: A contemporary approach to interpretation.* Boston: Allyn & Bacon.

Flanagan, D. P., & Ortiz, S. O. (2001). *Essentials of cross-battery assessment.* New York: John Wiley & Sons.

Flanagan, D. P., Ortiz, S. O., Alfonso, V. C., & Mascolo, J. T. (2002). *The achievement test desk reference (ATDR): A comprehensive framework for LD determination.* Boston: Allyn & Bacon.

Fry, A. F., & Hale, S. (2001). Relationships among processing speed, working memory, and fluid intelligence in children. *Biological Psychology, 54* (1-3), 1-34.

Garcia, G. M., & Stafford, M. E. (2000). Prediction of reading by *Ga* and *Gc* specific cognitive abilities for low-SES White and Hispanic English-speaking children. *Psychology in the Schools, 37*, 227-235.

Goswami, U. (2000). Phonological and lexical processes. In M. L. Kamil, P. B. Mosenthal, P. D. Pearson, & R. Barr (Eds.), *Handbook of reading research* (Vol. III, pp. 251-267). Mahwah, NJ: Lawrence Erlbaum Associates.

Goswami, U., & Bryant, P. E. (1990). *Phonological skills and learning to read.* London: Erlbaum.

Hale, J. B., Fiorello, C. A., Kavanagh, J. A., Hoeppner, J. B., & Gaither, R. A. (2001). WISC-III predictors of academic achievement for children with learning disabilities: Are global and factor scores comparable? *School Psychology Quarterly, 16*, 31-55.

Horn, J. L., & Noll, J. (1997). Human cognitive capabilities: *Gf-Gc* theory. In D. P. Flanagan, J. L. Genshaft, & P. L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (pp. 53- 93). New York: Guilford.

Jackson, N. E., Donaldson, G. W., & Cleland, L. N. (1988). The structure of precocious reading ability. *Journal of Educational Psychology, 80*, 234-243.

Kail, R. (1991). Development of processing speed in childhood and adolescence. In H. W. Reese (Ed.), *Advances in child development and behavior* (Vol. 23, pp. 151-185). San Diego, CA: Academic Press.

Kail, R., & Hall, L. K. (2001). Distinguishing short-term memory from working memory. *Memory & Cognition, 29*(1), 1-9.

Kail, R., Hall, L. K., & Caskey, B. J. (1999). Processing speed, exposure to print, and naming speed. *Applied Psycholinguistics, 20*, 303-314.

Kaufman, A. S. (1994). *Intelligent testing with the WISC-III.* New York: John Wiley & Sons.

Kaufman, A. S., & Kaufman, N. L. (1985). The Kaufman Test of Educational Achievement. Circle Pines, MN: American Guidance Service.

Kavale, K. A., & Forness, S. R. (2000). Auditory and visual perception processes and reading ability: A quantitative reanalysis and historical reinterpretation. *Learning Disability Quarterly, 23*, 253-270.

Keith, T. Z. (1999). Effects of general and specific abilities on student achievement: Similarities and differences across ethnic groups. *School Psychology Quarterly, 14*, 239-262.

Licht, M. H. (1995). Multiple regression and correlation. In L. G. Grimm & P. R. Yarnold (Eds.), *Reading and understanding multivariate statistics* (pp. 19-64). Washington, DC: American Psychological Association.

Macmillan/McGraw-Hill. (1989). *Comprehensive Test of Basic Skills, Fourth Edition Technical bulletin 1.* Monterey, CA: Author.

Mastropieri, M. A., & Scruggs, T. E. (1997). Best practices in promoting reading comprehension in students with learning disabilities: 1976 to 1996. *Remedial and Special Education, 18*, 197-213.

McBride-Chang, C. (1996). Models of speech perception and phonological processing in reading. *Child Development, 67*, 1836-1856.

McGrew, K. S. (1993). The relationship between the Woodcock-Johnson Psycho-Educational Assessment Battery—Revised *Gf-Gc* cognitive clusters and reading achievement across the life-span. *Journal of Psychoeducational Assessment Monograph Series: Woodcock-Johnson Psycho-Educational Assessment Battery—Revised*, 39-53. Cordova,TN: Psychoeducational Corporation.

McGrew, K. S. (1997). Analysis of the major intelligence batteries according to a proposed comprehensive *Gf-Gc* framework. In D. P. Flanagan, J. L. Genshaft, & P. L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (pp. 131-150). New York: Guilford.

McGrew, K. S., & Flanagan, D. P. (1998). *The intelligence test desk reference (ITDR):* Gf-Gc *cross-battery assessment.* Boston: Allyn & Bacon.

McGrew, K. S., Flanagan, D. P., Keith, T. Z., & Vanderwood, M. (1997). Beyond *g*: The impact of *Gf-Gc* specific cognitive abilities research on the future use and interpretation of intelligence tests in the schools. *School Psychology Review, 26*, 189-210.

McGrew, K. S., & Hessler, G. L. (1995). The relationship between the WJ-R *Gf-Gc* cognitive clusters and mathematics achievement across the life-span. *Journal of Psychoeducational Assessment, 13*, 21-38.

McGrew, K. S., & Knopik, S. N. (1993). The relationship between the WJ-R *Gf-Gc* cognitive clusters and writing achievement across the life-span. *School Psychology Review, 22*, 687-695.

McGrew, K. S., Werder, J. K., & Woodcock, R. W. (1991). *Woodcock-Johnson Psycho-Educational Battery—Revised technical manual.* Chicago: Riverside Publishing.

McGrew, K. S., & Woodcock, R. W. (2001). *Technical manual: Woodcock-Johnson III.* Itasca, IL: Riverside Publishing.

McGrew, K. S., & Wrightson, W. (1997). The calculation of new and improved WISC-III subtest reliability, uniqueness, and general factor characteristic information through the use of data smoothing procedures. *Psychology in the Schools, 34*, 181-195.

Meyer, M. S., Wood, F. B., Hart, L. A., & Felton, R. H. (1998). Selective predictive value in rapid automatic naming in poor readers. *Journal of Learning Disabilities, 31*, 106-117.

Morris, R. D., Shaywitz, S. E., Shankweiler, D. P., Katz, L., Steubing, K. K., Fletcher, J. M., Lyon, G. R., Francis, D. J., & Shaywitz, B. A. (1998). Subtypes of reading disability: Variability around a phonological core. *Journal of Educational Psychology, 90*, 347-373.

Necka, E. (1999). Learning, automaticity, and attention: An individual-differences approach. In P. L. Ackerman, P. C. Kyllonen, & R. D. Roberts (Eds.), *Learning and individual differences* (Vol. 7, pp. 161-184). Washington, DC: American Psychological Association.

Neuhaus, G., Foorman, B. R., Francis, D. J., & Carlson, C. D. (2001). Measures of information processing in rapid automatized naming (RAN) and their relation to reading. *Journal of Experimental Child Psychology, 78*, 359-373.

Oakhill, J., Yuill, N., & Parkin, A. (1986). On the nature of the difference between skilled and less-skilled comprehenders. *Journal of Research in Reading, 9*, 80-91.

Perfetti, C. A., Beck, I., Bell, L., & Hughes, C. (1987). Phonemic knowledge and learning to read are reciprocal: A longitudinal analysis of first grade children. *Merrill-Palmer Quarterly, 33*, 283-319.

Rasinski, T. V. (2000). Speed does matter in reading. *Reading Teacher, 54*(2), 146-151.

Rindermann, H., & Neubauer, A. C. (2000). Speed of information processing and success at school: Do basal measures of intelligence have predictive validity? *Diagnostica, 46*(1), 8-17.

Santos, O. B. (1989). Language skills and cognitive processes related to poor reading comprehension performance. *Journal of Learning Disabilities, 22*, 131-133.

Scarborough, H. S. (1998). Predicting the future achievement of second graders with reading disabilities: Contributions of phonemic awareness, verbal memory, rapid naming, and IQ. *Annals of Dyslexia, 48*, 115-136.

Snow, C. E., Burns, M. S., & Griffin, P. (1998). *Preventing reading difficulties in young children.* Washington, DC: National Academy Press.

Stahl, S. A., & Murray, B. A. (1994). Issues involved in defining phonological awareness and its relation to early reading. In J. L. Metsala & L. C. Ehri (Eds.), *Word recognition in beginning literacy* (pp. 65-87). Mahwah, NJ: Lawrence Erlbaum Associates.

Stanovich, K. E. (1986). Matthew effects in reading: Some consequences of individual differences in the acquisition of literacy. *Reading Research Quarterly, 21*, 360-406.

Stanovich, K. E. (1988). Explaining the differences between the dyslexic and garden-variety poor reader: Phonological-core variable-difference model. *Journal of Learning Disabilities, 21*, 590-612.

Stanovich, K. E. (1992). Speculations on the causes and consequences of individual differences in early reading acquisition. In P. B. Gough, L. C. Ehri, & R. Treiman (Eds.), *Reading acquisition* (pp. 307-342). Hillsdale, NJ: Lawrence Erlbaum Associates.

Stanovich, K. E., & Siegel, L. S. (1994). Phenotypic performance profile of children with reading disabilities: A regression-based test of the phonological-core variable-difference model. *Journal of Educational Psychology, 56*, 24-33.

Stanovich, K. E., Siegel, L. S., & Gottardo, A. (1997). Converging evidence for phonological and surface subtypes of reading disability. *Journal of Educational Psychology, 89*, 114-127.

Stothard, S. E., & Hulme, C. (1992). Reading comprehension difficulties in children: The role of language comprehension and working memory skills. *Reading and Writing, 4*, 245-256.

Torgeson, J. K., Wagner, R. K., Rashotte, C. A., Burgess, S., & Hecht, S. (1997). Contributions of phonological awareness and rapid automatic naming ability to the growth of word-reading skills in second- to fifth-grade children. *Scientific Studies of Reading, 1*, 161-185.

Vellutino, F. R., Scanlon, D. M., & Lyon, R. G. (2000). Differentiating between difficult-to-remediate and readily remediated poor readers: More evidence against the IQ-achievement discrepancy definition of reading disability. *Journal of Learning Disabilities, 33*, 223-238.

Vellutino, F. R., Scanlon. D. M., Sipay, E. R., Small, S. G., Pratt, A., Chen, R., & Denckla, M. B. (1996). Cognitive profiles of difficult-to-remediate and readily remediated poor readers: Early intervention as a vehicle for distinguishing between cognitive and experimental deficits as basic causes of specific reading disability. *Journal of Educational Psychology, 88*, 601-638.

Wagner, R. K., Torgeson, J. K., & Rashotte, C. A. (1994). Development of reading-related phonological processing abilities: New evidence of bidirectional causality from a latent variable longitudinal study. *Developmental Psychology, 30*, 73-87.

Wagner, R. K., Torgeson, J. K., Rashotte, C. A., Hecht, S. A., Barker, T. A., Burgess, S. R., Donahue, J., & Garon, T. (1997). Changing relations between phonological processing abilities and word-level reading as children develop from beginning to skilled readers: A 5-year longitudinal study. *Developmental Psychology, 33*, 468-479.

Wechsler, D. (1974). Wechsler Intelligence Scale for Children—Revised. New York: The Psychological Corporation.

Wechsler, D. (1991). Wechsler Intelligence Scale for Children—Third Edition. San Antonio, TX: The Psychological Corporation.

Wechsler, D. (1992). Wechsler Individual Achievement Test. San Antonio, TX: The Psychological Corporation.

Weiler, M. D., Harris, N. S., Marcus, D. J., Bellinger, D., Kosslyn, S. M., & Waber, D. P. (2000). Speed of information processing in children referred for learning problems: Performance on a visual filtering test. *Journal of Learning Disabilities, 33*, 538-550.

Wilkinson, L. (1990). *SYSTAT 10: Graphics.* Chicago: SYSTAT.

Williams, P. C., McCallum, R. S., & Reed, M. T. (1996). Predictive validity of the Cattell-Horn *Gf-Gc* constructs

to achievement. *Journal of Psychoeducational Assessment, 3,* 43-51.
Willows, D. M., Kruk, R. S., & Corcos, E. (Eds.). (1993). *Visual processes in reading and reading disabilities.* Hillsdale, NJ: Lawrence Erlbaum Associates.
Windfuhr, K. L., & Snowling, M. J. (2001). The relationship between paired associate learning and phonological skills in normally developing readers. *Journal of Experimental Child Psychology, 80,* 160-173.
Wolfe, M., Bowers, P. G., & Biddle, K. (2000). Naming-speed processes, timing, and reading: A conceptual review. *Journal of Learning Disabilities, 33,* 387-407.
Woodcock, R. W. (1978). *Development and standardization of the Woodcock-Johnson Psycho-Educational Battery.* Allen, TX: DLM Teaching Resources.
Woodcock, R. W. (1990). Theoretical foundations of the WJ-R measures of cognitive ability. *Journal of Psychoeducational Assessment, 8,* 231-258.
Woodcock, R. W. (1993). An information processing view of the *Gf-Gc* theory. *Journal of Psychoeducational Assessment Monograph Series: Woodcock-Johnson Psycho-Educational Battery—Revised,* 80-102. Cordova, TN: Psychoeducational Corporation.
Woodcock, R. W. (1998). Extending *Gf-Gc* theory into practice. In J. J. McArdle & R. W. Woodcock (Eds.), *Human cognitive abilities in theory and practice* (pp. 137-156). Mahwah, NJ: Lawrence Erlbaum Associates.
Woodcock, R. W., & Dahl, M. N. (1971). *A common scale for the measurement of person ability and test items difficulty* (AGS Paper No. 10). Circle Pines, MN: American Guidance Service.
Woodcock, R. W., & Johnson, M. B. (1989). Woodcock-Johnson Psycho-Educational Battery—Revised. Chicago: Riverside Publishing.
Woodcock, R. W., & Mather, N. (2001). *Woodcock-Johnson III Tests of Achievement examiner's manual.* Itasca, IL: Riverside Publishing.
Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). Woodcock-Johnson Psychoeducational Battery—Third Edition. Itasca, IL: Riverside Publishing.

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