Cattell–Horn–Carroll Cognitive Abilities and Their Effects on Reading Decoding Skills: *g* Has Indirect Effects, More Specific Abilities Have Direct Effects

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This study employed structural equation modeling to examine the effects of Cattell–Horn–Carroll (CHC) abilities on reading decoding skills using five age-differentiated subsamples from the standardization sample of the Woodcock–Johnson III (Woodcock, McGrew, & Mather, 2001). Using the Spearman Model including only g*, strong direct effects of* g *on reading decoding skills were demonstrated at all ages. Using the Two-Stratum Model including* g *and broad abilities, direct effects of the broad abilities Long-Term Storage and Retrieval, Processing Speed, Crystallized Intelligence, Short-Term Memory, and Auditory Processing on reading decoding skills were demonstrated at select ages. Using the Three-Stratum Model including* g*, broad abilities, and narrow abilities, direct effects of the broad ability Processing Speed and the narrow abilities Associative Memory, Listening Ability, General Information, Memory Span, and Phonetic Coding were demonstrated at select ages. Across both the Two-Stratum Model and the Three-Stratum Model at all ages,* g *had very large but indirect effects. The findings suggest that school psychologists should interpret measures of some specific cognitive abilities when conducting psychoeducational assessments designed to explain reading decoding skills.*

Keywords: reading decoding skills, general intellingence, cognitive abilities, CHC theory, reading aptitudes

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The term *reading decoding skills* describes the ability to recognize and decode words and regularly spelled psuedowords presented in isolation (Compton, 2000; Gough & Tunmer, 1986; Perfetti, 1994; Shankweiler et al., 1999). Numerous publications have described the individual differences in cognitive ability that affect the acquisition and development of reading decoding skills (e.g., Hoskyn & Swanson, 2000; Morris et al., 1998; Snow, Burns, & Griffin, 1998; Stuebing et al., 2002). Four groups of cognitive abilities have received the most attention. First, research findings have implicated the pivotal role that abilities related to the perception, discrimination, and manipulation of individual units of sound play in early reading skill development and reading failure. Terms for these abilities have included phonemic awareness, phonological awareness, phonological analysis and synthesis, and speech perception (see Scarborough & Brady, 2002).

Second, the construct system dealing with the temporary storage of information and processing or manipulation of that information in immediate awareness has been implicated as important for reading. Individual differences in the speech-based component of this system have been described as verbal short-term memory, phonological memory, immediate memory, and working memory (see Swanson, 2000). Third, the ability to

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access information (such as letter or color names) rapidly from the semantic lexicon has been reported to be an important aptitude for reading decoding skills. Terms such as rapid automatic naming, serial naming, phonological retrieval, and rate of access to phonological information in long-term memory have been used to describe this ability (see Wolfe, Bowers, & Biddle, 2000). Finally, abilities associated with comprehension of spoken language have long been reported to be associated with reading success and failure. Terms such as verbal intelligence, crystallized intelligence, vocabulary and syntactical knowledge, semantic processing, lexical processing, receptive vocabulary, listening comprehension, and verbal reasoning have been used to describe these abilities (see Goswami, 2000).

COGNITIVE ABILITY RESEARCH AND READING

Given the prevailing view that the IQ–achievement discrepancy has limited utility in the identification of children with learning disabilities, it is important to identify the role that measures of specific cognitive abilities have in identification and treatment of such learning difficulties (see Sternberg & Grigorenko, 2002, and Stuebing et al., 2002). For example, researchers studying alternate identification strategies for children with severe difficulties with reading decoding skills, such as failure to respond to empirically validated interventions, have implicated some cognitive abilities as important (see Al Otaiba & Fuchs, 2002, and Torgesen, 2000). It is incumbent that school psychology researchers and practitioners better understand the full range of cognitive abilities and their relative importance to the growth and maintenance of reading decoding skills.

There are at least two challenges that must be faced to achieve better understanding. The first challenge is a lack of a widely accepted and coherent framework for describing and measuring cognitive abilities. Without a guiding framework, the labeling of cognitive abilities in research and practice will likely be inconsistent, and cognitive ability assessment batteries used in research and practice may be redundant, incomplete, or both. The second challenge involves clarifying of the role and influence of general intelligence (*g*) on reading decoding skill development. It seems important to include measures of *g* in predictive research because of their strong relations with a number of socially important variables, including academic attainments (e.g., grades and years of schooling), occupational and social status, job performance, and income (Godttfredson, 1997; Jensen, 1998; Neisser et al., 1996). In addition, the relation between measures of *g* and individual differences in the rate of learning is robust (Jensen, 1989, 1998). Despite these findings, the nature and organization of *g* has rarely been recognized and specified in research examining the relations between cognitive abilities and reading decoding skills. Although some studies include measures of *g*, such as IQs or other global ability composites, this ability is rarely represented by a higher-order latent variable accounting for the shared variance among lower-order cognitive abilities.

To provide evidence of these two challenges, Table 1 includes a summary of the extant latent-variable research examining cognitive abilities that may explain the reading decoding skills of children. It is evident in Table 1 that a wide variety of cognitive abilities have been represented across over a dozen studies and that there is little consistency in the ability labels used across them. It is notable that many of the studies included in Table 1 reported the positive correlations between the first-order factors representing specific cognitive abilities, indicating that a general factor, and perhaps the *g* factor, may be present. However, only four studies reported in Table 1 included a higher-order *g* factor. It is probable that the lack of a standard nomenclature for cognitive abilities and the questions regarding the appropriateness of *g* in ability measurement has lead to confusion among researchers and practitioners with regard to the role that these abilities should play. To meet these challenges, a roadmap that describes the relations between general and specific cognitive abilities and reading achievement would be useful.

CATTELL–HORN–CARROLL THEORY OF COGNITIVE ABILITIES

Perhaps the most comprehensive and research-based model of human cognitive abilities is the Cattell–Horn–Carroll (CHC) theory (McGrew, 2005; McGrew & Flanagan, 1998; Woodcock, McGrew, & Mather, 2001). CHC theory is a synthesis of the extended *Gf-Gc* theory (Horn & Blankson, 2005; Horn & Masunuga, 2000) and the three-stratum theory of cognitive abilities (Carroll, 1993, 1997, 2003). The CHC theory describes a hierarchical framework of cognitive abilities that vary according to level of generality: narrow abilities (stratum I), broad abilities (stratum II), and *g* (stratum III). Narrow abilities include approximately 70 abilities that are limited in scope and specialized. Broad abilities include Fluid Reasoning, Crystallized Intelligence, Short-Term Memory, Visual Processing, Auditory Processing, Long-Term Storage and Retrieval, Processing Speed, Reading and Writing, Quantitative Knowledge, and Reaction Time/Decision Speed. At the

Table 1. Latent-Variable Research Examining the Relations between Cognitive Ability Predictors and Reading Decoding Skills

Authors and date	Age or grade range	Sample size	Study type	Latent-variable cognitive abilities	Relations reported between latent-variable cognitive abilities
Butler, Marsh, Sheppard, & Sheppard (1985)	K-G 6	—	L	Psycholinguistic Abilities, figure drawing, language, rhythm, perceptual motor skills, spatial/form perception	Correlations
Wagner, Torgesen, & Rashotte (1994)	K-G 2	244	L	Phonological Analysis, phonological synthesis, phonological coding in working memory, isolating naming, serial naming, vocabulary, prior word-level reading	Correlations
McGrew, Flanagan, Keith, & Vanderwood (1997); Vanderwood, McGrew, Flanagan, and Keith (2002)	G 1-12	> 200 at each level	C	General Intelligence, fluid reasoning, crystallized intelligence, visual processing, auditory processing, processing speed, short-term memory, long-term retrieval	Second-order factor
Wagner et al. (1997)	K-G 4	216	L	Phonological Analysis, phonological synthesis, phonological awareness, phonological memory, phonological naming, prior word-level reading	Second-order factor for phonological awareness only
de Jong & van der Leij (1999)	G 1-2	166	L	Nonverbal Intelligence, word knowledge, phonological awareness, verbal working memory, rapid naming, letter knowledge, prior reading achievement	Correlations, second-order factor
Keith (1999)	G 1-12	> 200 at each level	C	General Intelligence, fluid reasoning, crystallized intelligence, visual processing, auditory processing, processing speed, short-term memory, long-term retrieval	Second-order factor
Flanagan (2000)	G 3-4	166	C	General Intelligence, verbal comprehension, perceptual organization, freedom from distractibility, fluid reasoning, lexical knowledge/general information, visual processing, phonetic coding, perceptual speed, memory span, associative memory	Second-order factor
Lonigan, Burgess, & Anthony (2000)	A 2-5	S1 = 96	L	S1: Phonological Sensitivity, oral language, nonverbal cognitive abilities	Correlations
		S2 = 97		S2: Phonological Sensitivity, letter knowledge, environmental print	
Carver & David (2001)	G 3-6 G 4-5	S1 = 55 S2 = 83	C	Efficiency level, accuracy level, rate level, verbal knowledge level, pronunciation knowledge level, cognitive speed level, verbal knowledge aptitude, pronunciation knowledge aptitude	Correlations
Storch & Whitehurst (2002)	P-G 2	626	L	Reading, code-related skills, oral language skills	—
Nagy, Berninger, Abbott, Vaughan, & Vermeulen (2003)	G 2-4	S1 = 98 S2 = 97	C	Phonology, orthography, morphology, oral vocabulary	Correlations
Tiu, Thompson, & Lewis (2003)	—	124	C	Processing Speed, performance IQ	—
Oh, Glutting, Watkins, Youngstrom, & McDermott (2004)	A 6-16	1,116	C	General Intelligence, verbal comprehension, perceptual reasoning, freedom from distractibility, processing speed	Second-order factor

Note. A = Age; G = Grade; P = Preschool; S1 = Study 1; S2 = Study 2; L = Longitudinal; C = Cross-sectional.

apex of this hierarchical model is *g*.[1] The CHC theory provides researchers and practitioners with a standard nomenclature that can facilitate scholarly exchanges regarding the role of cognitive abilities in the acquisition and maintenance of reading skills (McGrew, 1997).

PURPOSE OF THE STUDY

To extend the research examining the effects of CHC general, broad, and narrow abilities on reading decoding skills, this study sought to answer three questions. First, which CHC cognitive abilities best explain reading decoding skills? Second, what is the magnitude of the effects of CHC cognitive abilities on reading decoding skills? Third, how do cognitive ability effects change from the preschool years through early adulthood? To address these questions, this study employed structural equation modeling (SEM) to develop, evaluate, and validate models specifying general and more specific cognitive abilities as influences on reading decoding skills.

One set of models (the Spearman Model) was specified to include *g* as the only influence on reading decoding skills. A second set of models (the Two-Stratum Model) was specified to include *g* and seven CHC broad abilities as influences on reading decoding skills. A third set of models (the Three-Stratum Model) was specified to include *g*, CHC broad abilities, and CHC narrow abilities as influences on reading decoding skills. SEM offers a number of advantages over other statistical analyses examining the relations between variables, such as multiple regression. SEM allows for (a) consideration of latent variables that have been cleansed of error, (b) the simultaneous estimation of both direct and indirect effects between variables, and (c), in the case of this research, the inclusion of two or three strata of cognitive abilities in the causal models (see Keith, 2005).

METHOD

Participants

Participants were drawn from the standardization sample of the Woodcock–Johnson III (WJ III; Woodcock et al., 2001). The WJ III standardization sample was constructed using a stratified sampling plan

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[1] The existence of a single higher-order general factor (*g*) is the focus of much debate—even among namesakes of the CHC theory (e.g., Carroll, 2003, and Horn & Blankson, 2005; for a review, see McGrew, 2005).

that controlled for 10 individual (e.g., race, sex, educational level, occupational status) and community (e.g., community size, community socioeconomic status [SES]) variables as described by the United States Census projections for the year 2000. For this study, five age-based samples were formed from the total standardization sample (McGrew & Woodcock, 2001). Age-ranges and sample sizes were as follows: 5 to 6 (n = 639), 7 to 8 (n = 720), 9 to 13 (n = 1995), 14 to 19 (n = 1615), and 20 to 39 (n = 1,409). These age-based samples roughly represent children in kindergarten and first grade, children in second and third grade, children in upper elementary and middle school, adolescents in high school, and college students and young adults. For the purpose of cross-validation of the models (see MacCallum, Roznowski, Mar, & Reith, 1994), each age-based sample was randomly split into a calibration sample and a validation sample. The last three rows of Table 2 provide more information about sample sizes for the calibration and validation samples.

Measures

All measures stemmed from the WJ III test batteries. The development, standardization, and psychometric properties of these test batteries have generally been evaluated favorably by independent reviewers (Bradley-Johnson, Morgan, & Nutkins, 2004; Cizek, 2003; Sandoval, 2003; Sares, 2005; Thompson, 2005). Means and standard deviations for all WJ III tests and all samples are shown in Table 2.

Cognitive Ability Tests

This study used 18 tests from the WJ III Tests of Cognitive Abilities, 4 tests from the WJ III Tests of Achievement (ACH), and 6 tests and 1 special composite from the WJ III Diagnostic Supplement (Woodcock, McGrew, Mather, & Schrank, 2003) as indicators of CHC cognitive abilities. The special composite is Numerical Reasoning, which represents a combination of Number Series and Number Matrices tests.[2] McGrew and Woodcock (2001) and Woodcock et al. (2003) reported estimates of reliability and evidence of validity for the resulting measures. All but three measures demonstrated median reliability coefficients of .80 or greater for

[2] At the time the data sets used in this study were constructed, these tests produced only a single score (Woodcock et al., 2003). The Numerical Reasoning composite will subsequently be referred to as a test for reader ease.

ages 5 to 39. These exceptions include Picture Recognition (*Mdn* = .76), Cross Out (*Mdn* = .72), and Incomplete Words (*Mdn* = .78).

Reading Tests

This study used two tests from the WJ III ACH as indicators of reading decoding skills. Letter–Word Identification measures letter and word recognition skills. Examinees are required to identify and name printed letters and to pronounce words. Word Attack measures skills in applying phonetic and structural analysis skills necessary for reading decoding skills. Examinees are required to identify letters after hearing the sound they typically make, to produce the sounds typically made by letters, and to pronounce phonically regular nonwords. McGrew and Woodcock (2001) reported estimates of reliability and evidence of validity.[3] For ages 5 to 39, the median reliability coefficient for Letter–Word Identification was .92, and for Word Attack, it was .87.

Analysis and Theoretical Models

Amos 5.0 (Arbuckle & Wothke, 2004) was used to analyze the specified latent variable SEM models. Maximum likelihood estimation was employed to estimate free parameters in the theoretical models presented below. Correlations and standard deviations for each age-based calibration sample and validation sample were the input for Amos; covariance matrices were analyzed. Calibration and validation matrices are available from the first author by request.

Correlations and standard deviations were estimated using the missing values subprogram from Statistical Package for Social Sciences (SPSS); the EM algorithm was used to estimate the matrix in the presence of incomplete data (Schafer & Graham, 2002). The last three rows of Table 2 show information about missing data. The value listed for "Minimum *n*" is the minimum number of participants for any given variable, whereas "Maximum *n*" shows the maximum number of cases across variables. The row labeled "% Missing" lists the percentage of data that were missing for each sample. In regards to

[3] Letter–Word Identification and Word Attack form the Basic Reading Skills cluster from the WJ III (Woodcock et al., 2001). Versions of these same tests also formed the Basic Reading Skills cluster from the Woodcock–Johnson Psycho-Educational Battery–Revised: Tests of Achievement (Woodcock & Johnson, 1989) and the Woodcock Reading Mastery Tests–Revised (Woodcock, 1998). Thus, validity evidence supporting this WJ III cluster and its test stems from these batteries as well.

Table 2. Means and Standard Deviations for the WJ III Tests, Sample Size Ranges, and Percentage of Missing Data for the Calibration Samples and the Validation Samples across Five Age Groups

	Ages 5 to 6				Ages 7 to 8				Ages 9 to 13			
	C		V		C		V		C		V	
WJ III test	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Numerical Reasoning	98.0	13.1	96.8	13.0	99.5	13.9	100.0	14.9	99.5	15.3	99.7	15.2
Concept Formation	98.5	14.3	98.8	15.6	99.6	15.2	99.7	14.8	99.0	15.6	99.8	14.7
Analysis–Synthesis	98.6	14.8	99.8	15.5	100.8	14.3	102.6	13.5	100.0	14.6	100.0	14.4
Block Rotation	101.2	16.0	100.8	17.7	102.3	11.3	102.2	11.3	99.5	12.7	99.5	12.2
Spatial Relations	100.7	12.4	98.9	13.4	101.1	11.4	99.8	11.9	99.1	12.1	99.3	13.4
Picture Recognition	99.2	14.5	99.7	13.5	98.3	13.3	100.1	12.2	99.9	12.9	99.1	13.2
Visual Matching	98.6	12.8	98.8	14.9	99.1	14.1	99.6	13.8	99.3	14.3	99.5	14.0
Decision Speed	97.7	13.8	98.2	13.8	98.4	13.6	99.5	13.7	99.6	14.6	99.4	14.5
Cross Out	97.5	12.7	97.3	13.0	98.9	13.9	99.1	14.1	99.8	14.1	99.8	14.6
Rapid Picture Naming	99.8	14.1	99.0	13.4	98.7	13.5	99.2	14.8	99.2	14.2	97.9	14.7
Retrieval Fluency	99.8	14.0	98.9	15.2	99.1	13.8	100.7	13.5	98.5	14.3	99.6	13.2
Visual–Auditory Learning: Delayed	98.0	14.9	98.0	15.5	100.4	15.4	99.5	14.7	99.3	14.9	99.6	15.1
Visual–Auditory Learning	98.9	15.0	99.0	14.0	100.9	13.8	100.8	12.8	99.9	13.4	99.8	14.1
Memory for Names	100.5	13.3	100.5	13.3	100.2	12.5	101.0	12.9	100.4	14.8	100.0	14.2
Memory for Names: Delayed	101.4	12.7	100.5	12.7	100.2	14.0	100.5	12.8	100.2	14.3	99.7	13.6
Sound Blending	97.6	14.1	98.5	14.0	99.6	13.6	100.2	14.7	98.8	14.6	99.3	15.1
Incomplete Words	98.2	15.0	99.7	13.8	99.2	13.4	99.3	15.0	99.1	14.3	99.6	13.7
Sound Patterns	98.2	15.7	99.3	14.7	99.7	14.7	100.8	14.8	99.3	14.7	101.3	14.9
Auditory Attention	100.4	15.7	101.1	15.8	103.0	14.0	101.2	13.0	100.5	13.4	100.3	13.8
Memory for Sentences	98.5	14.8	100.7	13.6	100.6	13.6	99.9	15.6	98.9	14.2	100.7	14.9
Memory for Words	98.9	13.7	99.8	15.0	99.6	13.5	99.6	15.1	98.9	14.2	100.3	14.7
Numbers Reversed	98.7	15.0	98.9	14.7	99.5	14.0	101.1	13.5	98.3	13.9	100.6	13.6
Auditory Working Memory	99.8	13.4	99.4	13.9	99.6	14.0	99.1	15.3	99.0	14.3	99.1	14.4
Verbal Comprehension	99.1	13.9	98.8	14.7	99.7	14.0	100.7	13.9	99.2	14.7	99.0	14.7
Picture Vocabulary	99.2	12.6	99.0	15.1	98.9	15.0	100.3	13.1	99.6	14.2	99.2	13.7
General Information	98.5	13.5	98.7	13.8	98.5	13.8	98.9	13.5	98.2	13.8	98.3	13.9
Academic Knowledge	99.6	13.4	98.8	14.9	99.5	13.6	100.3	14.0	99.1	14.1	99.2	14.1
Oral Comprehension	98.5	13.1	97.9	13.1	99.8	13.2	100.1	13.2	99.9	13.2	99.9	13.2
Story Recall	99.9	15.6	99.1	14.4	100.5	14.9	99.9	15.6	100.3	15.4	99.8	14.0
Letter–Word Identification	97.7	13.5	97.0	14.0	99.4	14.3	100.0	15.3	100.2	13.7	100.6	13.1
Word Attack	98.2	14.3	97.6	14.7	100.5	14.5	101.7	13.9	100.7	14.5	101.2	13.3
Minimum *n*	122		110		201		179		548		544	
Maximum *n*	318		321		363		357		1007		988	
% missing	15.6		18.0		18.3		16.0		18.0		15.4	

individual measured variables, scores for the Visual–Auditory Learning: Delayed test and the Auditory Attention test had the smallest sample sizes.

Spearman Model

Figure 1 presents the Spearman Model, which includes *g* as the sole influence on reading decoding skills. This model was used for analysis of all

Table 2. (*Continued*)

	Ages 14 to 19				Ages 20 to 39			
	C		V		C		V	
WJ III test	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Numerical Reasoning	99.2	14.5	100.0	15.0	101.5	12.6	101.0	12.7
Concept Formation	99.1	14.9	99.8	15.1	100.0	13.7	100.7	14.3
Analysis–Synthesis	99.7	13.6	100.1	14.1	100.6	13.7	100.9	14.0
Block Rotation	98.6	13.7	99.6	14.7	100.5	12.0	100.6	13.8
Spatial Relations	99.2	12.9	98.1	12.5	99.5	12.3	99.5	13.4
Picture Recognition	99.2	13.7	100.9	13.1	100.4	13.7	100.5	13.0
Visual Matching	99.8	14.1	99.3	14.4	100.5	12.4	101.0	13.0
Decision Speed	99.9	14.8	100.0	14.7	100.9	14.3	100.3	13.5
Cross Out	100.0	13.3	100.5	14.7	101.7	12.5	101.2	13.0
Rapid Picture Naming	99.6	15.4	100.6	14.9	102.6	13.8	101.3	13.8
Retrieval Fluency	99.8	14.0	99.1	13.5	101.2	12.5	100.9	11.9
Visual–Auditory Learning: Delayed	98.2	13.7	100.7	16.0	99.5	14.7	98.8	15.4
Visual–Auditory Learning	99.2	13.8	100.0	15.4	100.1	14.9	99.9	14.0
Memory for Names	98.3	14.7	100.8	15.3	101.2	15.3	99.8	14.7
Memory for Names: Delayed	98.6	14.6	101.2	16.1	102.2	15.4	100.1	14.5
Sound Blending	99.1	14.7	99.7	15.0	100.6	14.5	100.1	14.7
Incomplete Words	100.0	14.3	99.5	13.9	101.5	14.1	100.8	12.9
Sound Patterns	98.3	14.7	100.1	14.6	100.4	14.5	100.2	14.1
Auditory Attention	99.4	11.6	100.6	12.4	101.2	11.3	100.2	11.3
Memory for Sentences	99.2	14.4	100.1	14.8	100.4	12.8	99.7	13.3
Memory for Words	99.1	13.8	99.6	15.2	100.2	13.2	99.7	14.5
Numbers Reversed	98.7	14.1	99.8	14.0	100.2	13.4	100.7	13.7
Auditory Working Memory	99.9	14.9	99.6	13.8	101.8	12.6	102.4	12.4
Verbal Comprehension	98.8	14.7	100.6	14.5	100.7	13.8	99.8	13.9
Picture Vocabulary	99.4	13.6	99.6	14.4	100.0	14.3	98.9	14.2
General Information	99.3	14.3	99.6	14.5	100.9	13.5	100.1	14.0
Academic Knowledge	99.9	14.7	100.3	14.5	101.9	12.3	102.2	11.8
Oral Comprehension	99.7	13.5	99.8	13.1	100.0	13.5	99.4	14.1
Story Recall	99.3	15.0	99.8	14.6	100.4	13.9	100.2	13.6
Letter–Word Identification	99.4	13.1	99.7	13.9	100.9	12.0	100.6	12.0
Word Attack	99.2	14.0	100.2	14.3	101.2	12.5	100.1	12.8
Minimum *n*	411		387		349		368	
Maximum *n*	807		808		707		702	
% missing	21.1		20.2		24.8		21.9	

Note. C = calibration sample; V = validation sample.

five age groups. Consistent with standard SEM terminology, the model includes (a) the scores from the 29 WJ III cognitive ability tests, which are measured variables represented by rectangles on the left side of the figure, (b) the error and unique variances of the measured variables, which are represented by circles to the left of the rectangles, and (c) the first-order *g* factor, which is represented by the ellipse in the middle of the figure. The bottom right side of the figure presents the criterion or dependent variable portion of the model and includes (a) scores from the 2 WJ III reading tests (using rectangles), (b) the Reading Decoding Skills (RD) factor (using the ellipse), and (c) the error and unique variances of the reading tests and the unique variance of the RD factor (using circles).

The cognitive ability portion of the Spearman Model was developed to represent the factor structure first described by Spearman (1927). This model produces only a single common factor, which with such a wide variety of tests included in the model, can be considered the *g* factor (Carroll, 1993; Jensen, 1998). The portion of the model associated with the RD factor is consistent with the consensus definition of reading decoding skills and with research that has demonstrated significant covariation between letter and word recognition skills and the decoding of sounds from text (e.g., Carroll, 1993; Hoover & Gough, 1990; Perfetti, 1994; Shankweiler et al., 1999).

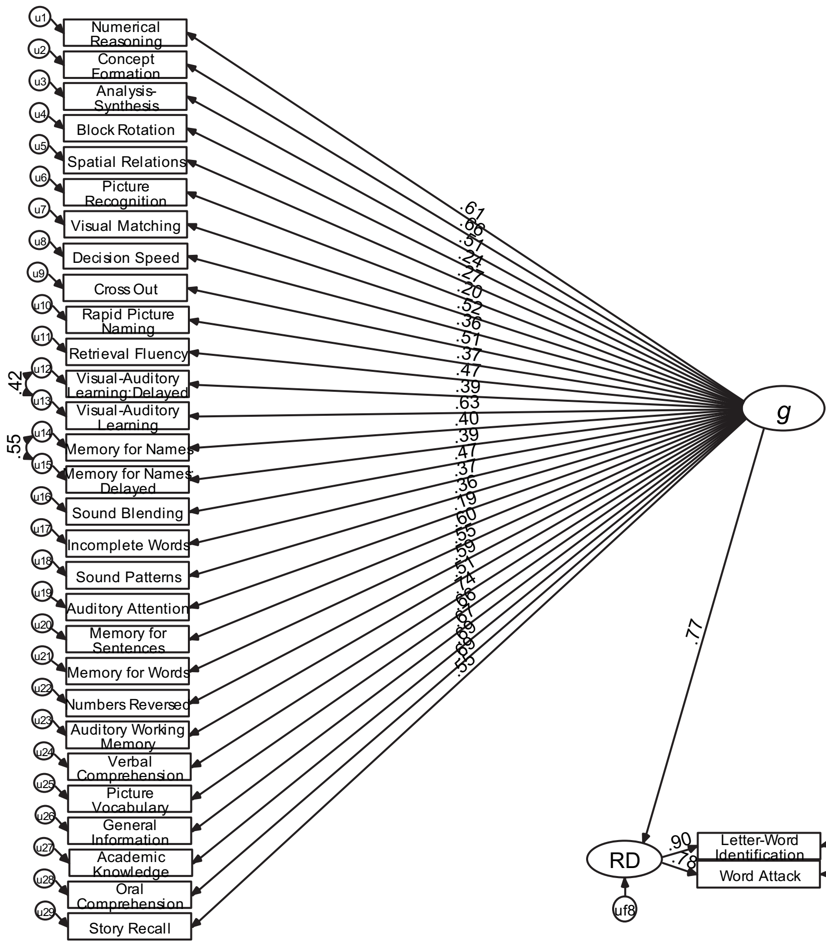

Figure 1. Spearman Model used in explanation of Reading Decoding Skills at ages 7 to 8. *g* = General Intelligence; RD = Reading Decoding Skills.

Structural models describe the relations between factors that are predictors (a.k.a., influences or independent variables) and at least one factor that is the outcome (a.k.a., the dependent variable). For the Spearman Model, only the structural path from the *g* factor to the RD factor was initially included. Modification indices were examined to determine if additional structural paths should be added. In order to validate or modify the models developed using the calibration samples, the second stage involved estimating the final model stemming from the calibration samples using the independent validation samples at each age level (MacCallum et al., 1994). Results from the final models using the validation samples are reported.

Two-Stratum Model

The left side of Figure 2 presents the cognitive ability portion of the Two-Stratum Model. This hierarchical model (Jensen, 1998) includes factors representing *g* and seven CHC broad abilities: Fluid Reasoning (Gf), Visual Processing (Gv), Processing speed (Gs), Long-Term Storage and Retrieval (Glr), Auditory Processing (Ga), Short-Term Memory (Gsm), and Crystallized Intelligence (Gc). This model was used for analysis of all five age groups.[4] Like the Spearman Model, the Two-Stratum Model includes variables representing scores from the cognitive ability tests and variables representing their unique variance and error. The Two-Stratum Model also includes (a) the first-order broad ability factors, which are represented by ellipses to the right of the rectangles, (b) the unique variances of the broad ability factors, which are represented by circles positioned above the broad ability factors, and (c) a second-order *g* factor that is represented by a single ellipse in the middle of the figure. Similar to the Spearman Model, the bottom right side of the figure presents the RD factor, its unique variance, the reading tests, and their unique variance and error.

The cognitive ability portions of the Two-Stratum Model were specified based on CHC theory. Recent empirical evidence for the models stems from SEM using the WJ III tests and exploratory and confirmatory factor analytic studies using earlier and current versions of many of the WJ III

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[4] There were four minor differences in the models across the five age groups stemming from slight differences in the match between the sample data and the model. The four sets of correlated error and unique variances for the measured variables shown in Figure 1 were included in all models except for those between the error and unique variances for Oral Comprehension and Academic Knowledge at ages 5 to 6, 14 to 19, and 20 to 39. Due to a path between the Long-Term Storage and Retrieval factor and the *g* factor that was greater than unity (a Heywood case) at ages 20 to 39, that path was set to a maximum of 1 by constraining the unexplained variance to 0.

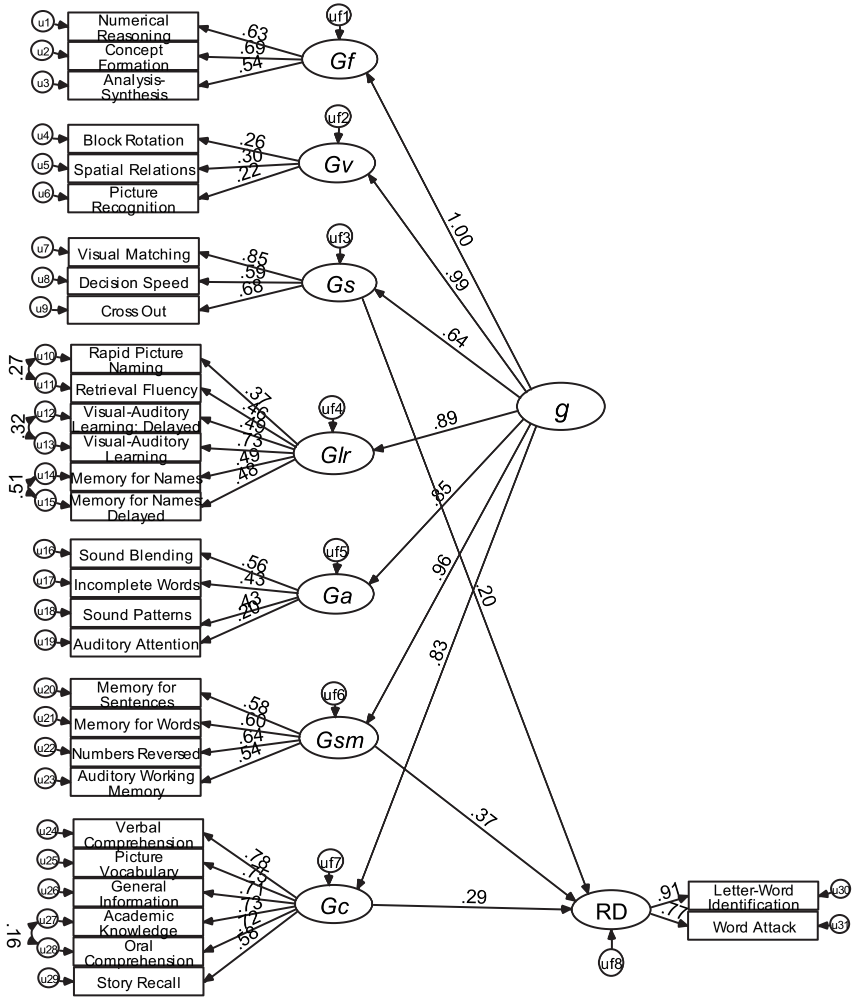

Figure 2. Two-Stratum Model used in explanation of Reading Decoding Skills at ages 7 to 8. Gf = Fluid Reasoning; Gv = Visual Processing; Gs = Processing Speed; Glr = Long-Term Storage and Retrieval; Ga = Auditory Processing; Gsm = Short-Term Memory; Gc = Crystallized Intelligence; *g* = General Intelligence; RD = Reading Decoding Skills.

tests (e.g., Carroll, 2003; Flanagan, 2000; McGrew & Woodcock, 2001; Phelps, McGrew, Knopik, & Ford, 2005). To ensure broad construct representation of the CHC broad abilities and adequate factor identification in the models, each broad ability factor was identified with at least three measures (Marsh, Hau, Balla, & Grayson, 1998).

A two-stage process of model development was used to examine the structural models describing the effects of the CHC general and broad abilities on reading decoding skills. The first stage involved an iterative process of testing structural models using the calibration sample for each age level. Using backward selection methods, initial models included all structural paths from the *g* factor and the seven broad ability factors to the RD factor. Backward selection methods were chosen to reduce specification error (pervasive in addition searches) by including all cognitive ability factors as predictors. After initial parameter estimates were obtained for a model, the structural path demonstrating the highest negative value was deleted, and the model was reestimated. This process of model estimation, pruning, and reestimation continued until all structural paths with negative parameter estimates were deleted. Following the same process, structural paths that were not statistically significant (at the .05 level) were deleted. Finally, modification indices were examined to determine if deleted structural paths should be added.

To validate the models developed using the calibration samples, the second stage involved estimating the final model from the calibration samples using the independent validation samples at each age level (MacCallum et al., 1994). Structural paths that were not statistically significant were deleted, and modification indices were examined to determine if deleted structural paths should be added. Results from the final models using the validation samples are reported.

Three-Stratum Model

The Three-Stratum Model, another hierarchical model (Jensen, 1998), is presented in Figure 3. The Fluid Reasoning (Gf), Visual Processing (Gv), Processing Speed (Gs), and RD factors and their indicators remain the same as in the Two-Stratum Model. However, the Long-Term Storage and Retrieval (Glr), Auditory Processing (Ga), Short-Term Memory (Gsm), and Crystallized Intelligence (Gc) factors were specified to subsume narrow ability factors. Long-Term Storage and Retrieval was specified to subsume the narrow abilities measuring fluency of retrieval of verbal information from memory (Naming Facility [NA]) and memory storage and retrieval during learning tasks (Associative Memory [MA]). Auditory Processing was specified to subsume narrow abilities measuring the ability to break apart or blend sounds in speech (Phonetic Coding [PC]) and the ability to discriminate between different sounds in speech under normal, distorted, or disruptive conditions (Speech–Sound Discrimination [US]/ Resistance to Auditory Stimulus Distortion [UR]). Short-Term Memory was specified to subsume narrow abilities measuring the passive retention

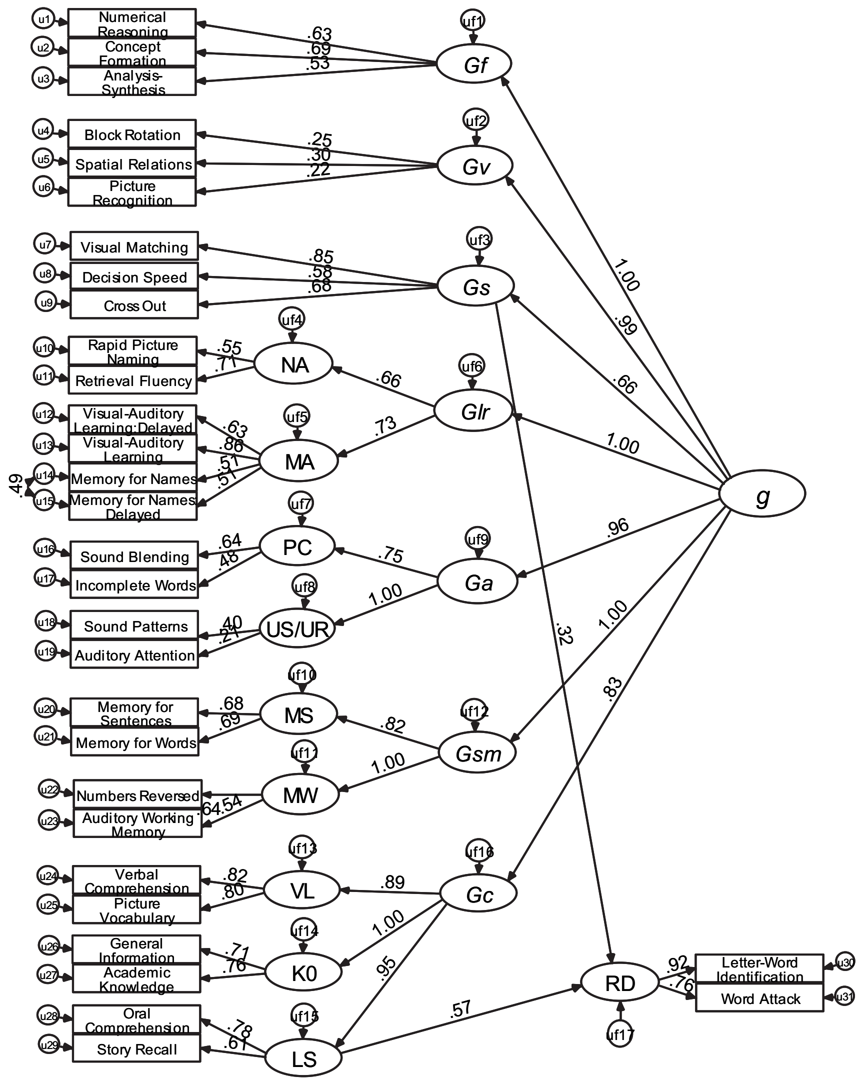

Figure 3. Three-Stratum Model used in explanation of Reading Decoding Skills at ages 7 to 8. Gf = Fluid Reasoning; Gv = Visual Processing; Gs = Processing Speed; Glr = Long-Term Storage and Retrieval; NA = Naming Facility; MA = Associative Memory; Ga = Auditory Processing; PC = Phonetic Coding; US/UR = Speech–Sound Discrimination/Resistance to Auditory Stimulus Distortion; Gsm = Short-Term Memory; MS = Memory Span; MW = Working Memory; Gc = Crystallized Intelligence; VL = Lexical Knowledge; LS = Listening Ability; K0 = General Information; *g* = General Intelligence; RD = Reading Decoding Skills.

of information in immediate memory (Memory Span [MS]) and the active transformation of information in immediate memory (Working Memory [MW]). Finally, Crystallized Intelligence was specified to subsume narrow abilities representing vocabulary knowledge (Lexical Knowledge [VL]), receptive language abilities (Listening Ability [LS]), and general or world knowledge (General Information [K0]). The Three-Stratum Model is supported by SEM research reported by McGrew and Woodcock (2001) and more recently by Phelps et al. (2005).

The model presented in Figure 3 was used during analysis of all five age groups with a few exceptions. Preliminary examination of this model across all calibration samples indicated that several narrow abilities demonstrated path coefficients greater than unity (1.0) on the broad abilities. As a result, the paths between the Working Memory factor and the Speech–Sound Discrimination/Resistance to Auditory Stimulus Distortion factor and their respective broad abilities were set to a maximum of 1 across all five age groups (by setting the unique variances of the broad ability factors to zero). The path between the General Information factor and the Crystallized Intelligence factor was set to a maximum of 1 at ages 7 to 8, 9 to 13, and 14 to 19, and the path between the Listening Ability factor and the Crystallized Intelligence factor was set to a maximum of 1 at ages 20 to 39. In addition to these instances, three broad ability factors demonstrated paths greater than unity from the *g* factor: Long-Term Storage and Retrieval at all ages, and Auditory Processing and Short-Term Memory at ages 5 to 6. All paths between these broad abilities and the *g* factor were set to a maximum of 1 at the appropriate age levels.

The two-stage process of model development and validation was completed using the Three-Stratum Model. Initial models included structural paths from the nine narrow ability factors, the three broad ability factors not subsuming narrow abilities, and the *g* factor to the RD factor. (Broad ability factors subsuming narrow ability factors were not included in the structural models.) After completing the iterative process of estimation, pruning, and reestimation, the final models stemming from the calibration samples at each age level were estimated using the validation samples. Structural paths that were not statistically significant at the .05 level were deleted, and modification indices were examined to determine if deleted structural paths should be added. Results from the final models using the validation samples are reported.

Fit Indices for Models

We used the Root Mean Square of Approximation (RMSEA) and the Standardized Root Mean Square Residual (SRMR) as the primary fit indices to judge the fit of single models at each age level. Current rules-of-thumb and simulation research (Hu & Bentler, 1998, 1999) suggest that RMSEAs below about .06 and SRMRs below about .08 suggest good fit of the model to the data. Of these fit indices, the SRMR is the most intuitively appealing because it represents the average difference in the actual correlation matrix used to estimate the model and the matrix that is implied by the model. The Tucker–Lewis index (TLI) and comparative fit index (CFI) are also reported, but we do not place much emphasis on them because they tend to demonstrate worse fit with models including a large number of variables, such as those used here (Kenny & McCoach, 2003). We used the Akaike Information Criterion (AIC) to compare the non-nested classes of models (e.g., the Spearman Model vs. the Two-Stratum Model) at each age level. Lower AIC values suggest better fit.

RESULTS

Spearman Model

At each age level, the structural path from the *g* factor to the RD factor was statistically significant using both the calibration samples and the validation samples. The top section of Table 3 presents relevant fit statistics for the final models across the five age groups. The RMSEA and the SRMR suggest the models fit the data reasonably well (Hu & Bentler, 1999).

For purposes of illustration, the final Spearman Model for ages 7 to 8 is shown in Figure 1. This figure includes the standardized path coefficients from the *g* factor to the RD factor. These standardized path coefficients, like beta weights from multiple regression, indicate the proportion of standard deviation units that the RD factor changes as a function of one standard deviation change in the *g* factor. Standardized coefficient effect sizes of .05 and above can be considered small effects, effect sizes around .15 can be considered moderate effects, and effect sizes above .25 can be considered large effects (cf. Keith, 1999, 2006; Pedhazur, 1997). For all age levels, when the direct effect of the *g* factor on the RD factor was specified, the effects were significant and large: .73 (ages 5 to 6), .77 (ages 7 to 8), .69 (ages 9 to 13), .82 (ages 14 to 19), and .88 (ages 20 to 39).

Table 3. Fit Statistics for Final Spearman Models, Two-Stratum Models, and Three-Stratum Models Across Five Age Groups

Model and age group	χ^2	*Df*	RMSEA (90% interval)	Standardized RMR	TLI	CFI	AIC
Spearman Model							
Ages 5 to 6	942.289	431	.059 (.054–.064)	.0578	.842	.854	1072.289
Ages 7 to 8	1219.780	431	.069 (.064–.073)	.0624	.795	.810	1349.780
Ages 9 to 13	2258.270	431	.074 (.071–.077)	.0599	.774	.790	2388.270
Ages 14 to 19	1992.829	431	.074 (.071–.078)	.0624	.792	.807	2052.829
Ages 20 to 39	1801.862	431	.078 (.074–.082)	.0630	.778	.794	1931.862
Two-Stratum Model							
Ages 5 to 6	651.392	422	.040 (.034–.044)	.0485	.928	.934	799.392
Ages 7 to 8	870.960	421	.052 (.047–.057)	.0543	.880	.891	1020.960
Ages 9 to 13	1227.273	421	.049 (.046–.053)	.0457	.898	.907	1377.273
Ages 14 to 19	1273.076	422	.057 (.053–.060)	.0519	.879	.890	1421.076
Ages 20 to 39	1334.084	424	.064 (.060–.068)	.0551	.850	.863	1478.084
Three-Stratum Model							
Ages 5 to 6	616.550	421	.037 (.030–.043)	.0474	.938	.944	766.550
Ages 7 to 8	811.885	421	.049 (.044–.054)	.0530	.896	.906	961.885
Ages 9 to 13	1143.476	419	.047 (.044–.050)	.0452	.908	.917	1297.476
Ages 14 to 19	1205.221	420	.055 (.051–.058)	.0508	.888	.898	1357.221
Ages 20 to 39	1241.668	419	.061 (.057–.065)	.0523	.863	.876	1395.668

Note. CFI = Comparative Fit Index; TLI = Tucker Lewis Index; RMSEA = Root Mean Square Error of Approximation; Standardized RMR = Standardized Root Mean Square Residual; AIC = Akaike Information Criterion.

Two-Stratum Model

All significant structural paths using the calibration samples were significant using the validation samples. No structural paths were added based on modification indexes. At ages 7 to 8 and 20 to 39, the paths from the *g* factor to the Fluid Reasoning factor were greater than unity, so they were set to a maximum of 1.

Table 3 presents relevant fit statistics for the final models across the five age groups. The RMSEA and the SRMR suggest that the models fit very well at each age level (Hu & Bentler, 1999). It is worth noting that the AIC values for the Two-Stratum Models were consistently lower than those for the Spearman Model, which suggests the superiority of the Two-Stratum Model across age levels.

The final structural model for the Two-Stratum Model for ages 7 to 8 is shown in Figure 2. This figure includes the standardized path coefficients from the CHC cognitive ability factors to the RD factor. As shown in Table 4, one of the most interesting findings was that for all age levels, the direct effect of the *g* factor on the RD factor was statistically nonsignificant. Instead, *g* had an indirect effect on the RD factor. In other words, *g* had direct effects on the broad ability factors, and in turn, some of these broad ability factors had direct effects on reading decoding skills. Thus, for the

Two-Stratum Model, the *g* factor demonstrated very large but indirect effects on RD factor for all five age groups (.64 to .81).

The effects of the broad abilities on reading decoding skills and the developmental changes in the effects of these abilities are important to note (see Table 4). For ages 5 to 6, the Long-Term Storage and Retrieval factor and the Processing Speed factor demonstrated large direct effects. For ages 7 to 8, the effects from the Processing Speed factor remained significant but declined notably in magnitude, and the effects from the Long-Term Storage and Retrieval factor became nonsignificant. Beginning at ages 7 to 8 and continuing through the three remaining age levels, the Crystallized Intelligence factor demonstrated large direct effects. In fact, at ages 14 to 19 and 20 to 39, Crystallized Intelligence demonstrated the strongest effect. Also beginning at ages 7 to 8, the Short-Term Memory factor demonstrated strong effects, but its effect was nonsignificant at ages 20 to 39. The Auditory Processing factor demonstrated strong effects at only this oldest age level.

Three-Stratum Model

All significant structural paths but one from the calibration samples were significant using the validation samples. At ages 7 to 8, the path from the Memory Span factor to the RD factor was not significant using the validation sample, so the path was deleted. No structural paths were added based on modification indexes. Using the validation sample, several paths between broad abilities and narrow abilities or between the *g* and broad abilities were greater than unity, so they were set to a maximum of 1. These paths included the following: Crystallized Intelligence to Listening Ability at ages 5 to 6, *g* to Fluid Reasoning at ages 7 to 8 and 20 to 39, and *g* to

Table 4. Standardized Indirect Effects of *g* and Standardized Direct Effects of CHC Broad Abilities on Reading Decoding Skills Across Five Age Groups for the Two-Stratum Model

	Age group				
Standardized effects	5 to 6	7 to 8	9 to 13	14 to 19	20 to 39
To reading decoding skills					
From g (indirect)	.74	.73	.64	.76	.81
From Gsm		**.37**	**.40**	**.37**	
From Gc		**.29**	**.34**	**.52**	**.58**
From Glr	**.49**				
From Gs	**.38**	**.20**			
From Ga					**.38**

Note. Direct effects are shown in boldface. g = General Intelligence; Gsm = Short-Term Memory; Gc = Crystallized Intelligence; Glr = Long-Term Storage and Retrieval; Gs = Processing Speed; Ga = Auditory Processing.

Short-Term Memory at ages 7 to 8. The AIC values for the Three-Stratum Model were consistently somewhat better than those for the Two-Stratum Model, and all fit statistics followed the same patterns as the Two-Stratum Model across age levels (see Table 3).

As evident in Table 5, *g* continued to demonstrate indirect effects on reading decoding skills in the Three-Stratum Model. Its indirect effects on reading decoding skills remained large, and they were similar in magnitude to those using the Two-Stratum Model. Not surprisingly, the effects of the broad abilities on reading decoding skills were similar to those from the Two-Stratum Model. For ages 5 and 6, the Associative Memory and Processing Speed factors demonstrated large direct effects, and the Long-Term Memory factor demonstrated indirect effects through Associative Memory. For ages 7 to 8, the effects from the Processing Speed factor were significant and large, but the effects of the Associative Memory factor were nonsignificant. Two narrow abilities subsumed by the Crystallized Intelligence factor demonstrated large direct effects. At ages 7 to 8, the Listening Ability factor demonstrated a strong effect, but beginning at age 9 to 13, the General Information factor demonstrated strong effects. Like the Two-Stratum Model, the indirect effects of Crystallized Intelligence and direct effects of its narrow abilities were the strongest influences on reading decoding skills. Consistent with the Two-Stratum Model, the Short-Term Memory factor demonstrated significant effects, but these effects were indirect through the Memory Span factor. In contrast, Memory Span did not

Table 5. Standardized Indirect Effects of *g* and Standardized Direct and Indirect Effects of CHC Broad and Narrow Abilities on Reading Decoding Skills Across Five Age Groups for the Three-Stratum Model

	Age group				
Standardized effects	5 to 6	7 to 8	9 to 13	14 to 19	20 to 39
To reading decoding skills					
From g (indirect)	.70	.67	.63	.75	.83
From Gsm (indirect)			.20	.34	.31
From MS			**.24**	**.36**	**.33**
From Gc (indirect)		.54	.52	.54	.52
From LS		**.57**			
From KO			**.52**	**.54**	**.53**
From Glr (indirect)	.37				
From MA	**.43**				
From Gs	**.46**	**.32**			
From Ga (indirect)					.13
From PC					**.16**

Note. Direct effects are shown in boldface. g = General Intelligence; Gsm = Short-Term Memory; MS = Memory Span; Gc = Crystallized Intelligence; LS = Listening Ability; K0 = General Information; Glr = Long-Term Storage and Retrieval; MA = Associative Memory; Gs = Processing Speed; Ga = Auditory Processing; PC = Phonetic Coding.

demonstrate a significant effect at ages 7 to 8, and its effect was notably lower at ages 9 to 13 than reported for the Two-Stratum Model. However, Memory Span demonstrated strong effects at ages 20 to 39, whereas these effects were nonsignificant using the Two-Stratum Model. Finally, at the oldest age level, the Phonetic Coding factor demonstrated moderate direct effects.

DISCUSSION

This study focused on the effects of CHC general, broad, and narrow cognitive abilities on reading decoding skills. Multiage data from the WJ III standardization sample (Woodcock et al., 2001) were analyzed using SEM and multiple measures of each ability construct. Results stemming from the parsimonious *g*-factor model indicated that *g* had strong direct effects, but other models including both general and broad abilities (the Two-Stratum Model) and models including general, broad, and narrow abilities (the Three-Stratum Model) provided better explanations of the effects of cognitive abilities on reading decoding skills. In both the Two-Stratum Model and the Three-Stratum Model, *g* had only indirect effects on reading decoding skills through the specific cognitive abilities. These results supported the following statement by McGrew, Flanagan, Keith, and Vanderwood (1997) that "both general and specific abilities are important in understanding reading. . .achievement" (p. 200). By considering the broad and narrow abilities that have been spotlighted in prior research as well as *g*, this study helps to explain in more detail how cognitive abilities affect reading decoding skills.

General Intelligence

Across all three types of models, *g* had large effects on reading decoding skills. However, when CHC broad and narrow abilities were included in the models, the effects of *g* were indirect through these specific abilities, rather than direct. In other words, the broad and narrow abilities mediated the effects of *g* on reading decoding skills. It is tempting to speculate that when *g* is included in SEM models, the broad and narrow abilities would have different, fewer, and smaller effects. That is, once *g* explains an important component of reading decoding skills, it could be supposed that the broad and narrow abilities would have little additional effect. However, when *g* was allowed to "compete" equally with the specific abilities as predictors of reading decoding skills in this study, the results indicated that this supposition was not supported. Results from the two best-fitting models specified in this study revealed consistent indirect effects of *g* and consistent direct effects of broad abilities or both broad abilities and narrow abilities. These findings suggest that it is not the case that either *g* alone or specific abilities alone affect reading decoding skills. Specific abilities affect reading decoding skills directly, but *g* affects reading decoding skills indirectly through these abilities.

Broad and Narrow Abilities

The five CHC broad abilities demonstrating significant effects on reading decoding skills in the Two-Stratum Model demonstrated similar effects in the Three-Stratum Model. These broad abilities included Auditory Processing, Short-Term Memory, Long-Term Storage and Retrieval, Crystallized Intelligence, and Processing Speed. In the Three-Stratum Model, the effects of four of these five broad abilities were mediated by CHC narrow abilities.

Auditory Processing

It was unexpected that the effects of Auditory Processing and the narrow ability Phonetic Coding on reading decoding skills were evident at only the oldest age level in this study. This finding was unexpected given the large body of contemporary research that has demonstrated links between early reading skill development and abilities associated with the perception, discrimination, and manipulation of individual units of sound (e.g., Goswami, 2000; Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997). In addition, previous SEM research guided by CHC theory (Flanagan, 2000; Keith, 1999; McGrew et al., 1997; Vanderwood, McGrew, Flanagan, & Keith, 2002) that employed tests from the Woodcock–Johnson Tests of Cognitive Ability—Revised (WJ-R; Woodcock & Johnson, 1989) demonstrated significant effects of Phonetic Coding on reading decoding skills during the school-age years.[5] A number of hypotheses are offered to account for these unexpected findings.

First, it is possible that the ability to process phonemes mentally may have been overstated in prior research, particularly given that prior read-

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[5] Although the factor we call Phonetic Coding here was labeled Auditory Processing by McGrew et al. (1997) and Vanderwood et al. (2002), we believe that the factor specified in these previous studies is more aptly a narrow ability factor (Phonetic Coding) than a broad ability factor (Auditory Processing).

ing-related research has typically included a more restricted range of ability constructs as possible explanatory variables (see Castles & Coltheart, 2004; Swanson, Trainin, Necechea, & Hammill, 2003). For example, some research suggests that variance present in tasks measuring phoneme processing abilities may be accounted for by more powerful predictors of reading decoding skills such as *g* and those associated with Short-Term Memory and Processing Speed (see McGrew, 2005).

Second, the findings from the current study may differ from previous CHC-designed research studies using SEM (Flanagan, 2000; Keith, 1999; McGrew et al., 1997; Vanderwood et al., 2002) because of different operational specifications of the reading factors. For example, in these four previous studies, the factors representing reading decoding skills were specified as factors reflecting reliable variance from individual tests (i.e., the WJ-R Letter–Word Identification and Word Attack tests; Woodcock & Johnson, 1989). In the current study, reading decoding skills were specified using a single factor representing the shared variance from revised versions of the same two tests used in these four previous studies: Letter–Word Identification and Word Attack from the WJ III (Woodcock et al., 2001). Thus, what is common between these two tests measuring reading decoding skills used in this study may differ somewhat from what is measured by each individual test and what was measured by previous versions of these two tests.

Finally, differences in the operationalization of the cognitive ability factors may also contribute to the current findings. For instance, Flanagan (2000); Keith (1999); McGrew et al. (1997), and Vanderwood et al. (2002) used similarly named Phonetic Coding factors formed from the WJ-R Tests Sound Blending and Incomplete Words (Woodcock & Johnson, 1989). The revised task requirements for the corresponding WJ III tests may have affected the abilities they measure (Woodcock et al., 2001). Both WJ III tests limit the presentation of each stimulus word to a single occurrence, whereas the WJ-R versions allowed for two presentations of each stimulus word. It is possible that the WJ III revisions may have increased the relative importance of attention and concentration on task performance and reduced the relative importance of phonemic processing abilities. At this time, the above hypotheses are speculative in nature, and future research is needed to determine if the current findings are replicated.

Short-Term Memory

The factors representing abilities associated with the temporary storage of information in immediate awareness demonstrated consistent direct effects on reading decoding skills, but these effects varied across models and age levels. Short-Term Memory demonstrated significant effects in both the Two-Stratum Model and the Three-Stratum Model. However, in the Three-Stratum Model, its effects were indirect through the narrow ability Memory Span. In contrast to the finding that Short-Term Memory had direct effects on reading decoding skills beginning at ages 7 to 8 in the Two-Stratum Model, Memory Span did not demonstrate a significant direct effect at ages 7 to 8 in the Three-Stratum Model. Similarly, the direct effect of Memory Span at ages 9 to 13 in the Three-Stratum Model was notably lower than the direct effect of Short-Term Memory at the same age level in the Two-Stratum Model. Furthermore, Memory Span demonstrated strong direct effects at ages 20 to 39 in the Three-Stratum Model, whereas the effects of Short-Term Memory were nonsignificant at the same age level in the Two-Stratum Model.

Consistent with some previous research, the findings from the Three-Stratum Model indicate that the narrow ability Memory Span is more important or more related to reading decoding skills than the narrow ability Working Memory (Swanson & Berninger, 1995). Whereas Memory Span, which may also be called phonological memory and verbal short-term memory, focus only on the storage of language-based information in immediate awareness, Working Memory focuses on the simultaneous storage of information and processing or manipulation of information in immediate awareness. Memory Span may have demonstrated significant effects on reading decoding skills in this study both because it represents the holding area for speech-based phonological information in conscious awareness and because adequate reading decoding, through subvocalization, leads such information to be placed in that holding area (see Perfetti, 1985).

Long-Term Storage and Retrieval

At the earliest age levels included in this study, the broad ability Long-Term Storage and Retrieval and the narrow ability Associative Memory had strong effects on reading decoding skills. This finding is consistent with some recent research (Evans, Floyd, McGrew, & Leforgee, 2002; Windfuhr & Snowling, 2001). However, in contrast to other research (see Wolfe et al., 2000), it was not the other narrow ability subsumed by the Long-Term Storage and Retrieval factor in the Three-Stratum Model—Naming Facility—that demonstrated effects on reading decoding skills. Naming Facility may represent the same ability to access information rapidly from the semantic lexicon that is touted in much reading research

(McGrew & Flanagan, 1998). Perhaps the finding of significant relations between Associative Memory and reading decoding skills is reflective of the nature of reading during kindergarten and the very early school years in which children memorize the pattern or shapes of letters forming the printed word. Frith (1985) has called this stage of reading the *logographic stage*, and Ehri (1992) has called it the *visual cue reading stage.* Furthermore, perhaps the finding partially reflects the nature of the earliest items on the WJ III reading tests. For example, the first six items from the Letter–Word Identification test requires examinees to point to letters that are named by the examiner. These items may have called upon the Associative Memory ability of nonreaders and emerging readers who were included in the youngest age group.

Crystallized Intelligence

Factors associated with the comprehension of spoken language and the breadth of world knowledge demonstrated strong, and developmentally increasing, direct effects on reading decoding skills. Whereas the broad ability Crystallized Intelligence demonstrated strong direct effects in the Two-Stratum Model, the narrow abilities Listening Ability and General Information demonstrated strong direct effects in the Three-Stratum Model. At ages 5 to 6, Listening Ability demonstrated significant effects, but beginning at ages 7 to 8 and continuing into adulthood, the direct effects of General Information were the largest of any broad or narrow ability. These findings indicate the importance of language-based declarative knowledge to reading decoding skills. More specifically, they draw attention to world knowledge (as represented by the General Information factor). They also indicate that vocabulary knowledge (as represented by the narrow ability Lexical Knowledge factor) is somewhat less important to reading decoding skills than General Information or Listening Ability. Perhaps Lexical Knowledge is important only as one indicator of the broad ability Crystallized Intelligence. It must be noted that it is likely that the direct effects of Crystallized Intelligence, Listening Ability, and General Information on reading decoding skills demonstrated in this study represent the interaction between reading itself and the consolidation of knowledge gained from reading.[6]

[6] Note that Carroll's (1993) analysis and review included both reading and writing abilities under the second-stratum ability Crystallized Intelligence.

Processing Speed

The finding of strong effects of Processing Speed at the two youngest age levels included in this study is consistent with prior CHC-organized reading research (Flanagan, 2000; McGrew et al., 1997; Williams, McCallum, & Reed, 1996) and with a wide array of research that indicates that Processing Speed is an important ingredient in the early stages of acquiring most cognitive or academic skills (Kail, 1991; Kail, Hall, & Caskey, 1999). In general, it is hypothesized that the more rapidly and efficiently an individual can automatize basic academic or cognitive operations, the more attention and cognitive resources can be allocated to higher-level aspects of task performance.

The finding of significant effects of Processing Speed on reading decoding skills at the earliest age levels in the Two-Stratum Model and the Three-Stratum Model may aid in explaining the absence of effects for Naming Facility, a narrow ability subsumed by Long-Term Storage and Retrieval in the Three-Stratum Model (see above). Tests measuring Processing Speed and tests measuring Naming Facility both stress the importance of the examinee's speed. It may be that when the broad ability of Processing Speed is included as an influence on reading decoding skills in Three-Stratum Model, the narrow ability Naming Facility has little unique explanatory variance to contribute beyond Processing Speed.

Visual Processing and Fluid Reasoning

The abilities associated with visual—perceptual and nonverbal reasoning abilities were not implicated as important influences on reading decoding skills at any age level using either model. This finding is consistent with a large body of research (Kavale & Foreness, 2000). It may be that when a full range of cognitive abilities, including *g*, is considered, these abilities are overshadowed by more important influences that are often missing in other studies due to model specification error (see Evans et al., 2002). It may also be that these abilities are important for reading only for individuals who demonstrate significant deficits in these areas.

LIMITATIONS AND STRENGTHS OF CURRENT STUDY

The interpretation of these findings should be tempered by at least four limitations. First, tests measuring cognitive abilities and tests measuring reading decoding skills in this study may share latent abilities and be factorially complex. For example, Word Attack, an indicator of the reading decoding skills factor in this research, may measure both the CHC broad ability of Reading and Writing and the narrow cognitive ability Phonetic Coding (McGrew, 1997; McGrew & Woodcock, 2001). Although these relations may represent causal effects, the possible predictor—criterion contamination in this study may magnify the predictive power of some cognitive ability factors. Second, data analyzed for this study were collected using a cross-sectional design and not a longitudinal design (see Table 1 for examples of studies employing these designs). Future research should determine if similar effects are shown when cognitive ability and reading decoding skills are assessed through other instruments and across time (with the same subjects). Third, although this study included a full range of CHC cognitive abilities as predictors of reading decoding skills, it may have omitted (a) other important cognitive abilities (e.g., orthographic knowledge and concepts about print) that are not included in CHC theory as well as (b) noncognitive variables, such as exposure to print materials in the home (Lonigan, Burgess, & Anthony, 2000; Nagy, Berninger, Abbott, Vaughn, & Vermeulen, 2003). Finally, it is possible that more complex models describing the interactions between CHC cognitive abilities may provide a clearer picture of the nature of the cognitive ability effects on reading decoding skills (see Conway, Cowan, Bunting, Therriault, & Minkoff, 2002, and McGrew, 2005). Additional research will no doubt lead to improvements and revisions of the models developed and tested in this research.

It is also worthwhile to review the advantages of this research. The models were developed based on both intelligence and reading theory and research, constructs were operationalized via multiple well-standardized and well-researched measures that were the same across all samples, and the models were estimated using a nationally representative sample of learners from multiple age levels. The research also used a calibration—validation approach in which models were developed on one sample and then tested on a second sample. Such an approach guards against the dangers of specification searches and should produce more stable, reproducible findings.

Implications

This study takes the middle ground in the "one-versus-many debate," which refers to the debate over preference for a single score measuring *g* or preference for a multitude of scores measuring specific cognitive abilities (McGrew et al., 1997). The results of this study point to the complex nature of reading decoding skills, the potential value of measures of multiple cognitive abilities in explaining reading decoding skills, and the importance in recognizing the differential importance of general and specific cognitive abilities in the development of reading decoding skills as a function of age. The results of the current study suggest that as the practice of school psychology moves away from using IQ–achievement discrepancies as the primary criterion for identifying learning disabilities, school psychologists and other professionals engaged in assessment should direct more attention on domain-specific, referral-focused assessments that employ well-operationalized measures of specific CHC abilities and measures of *g*.

Specific Cognitive Abilities

The current findings suggest that school psychologists should become more selective in designing assessments that are more sensitive to the domain-specific nature of reading-related referrals. The knee-jerk administration of a complete cognitive battery to individuals referred for problems with reading decoding skills is not supported by the current study. Instead, the administration of measures of CHC narrow abilities, which come closest to the core "psychological processes" deemed important to reading (see Floyd, 2005), is suggested.

However, even a domain-specific, referral-focused approach to assessment needs to be tempered by a number of cautions. First, although the Three-Stratum Model provides the best fit of the three models for each age group, as evident in Table 5, the magnitude of the standardized direct effects of narrow abilities on reading decoding skills and the corresponding indirect effects of the broad abilities are minimally different. This finding was anticipated based on the very large effects from the broad abilities to the narrow abilities in the Three-Stratum Model. These effects were often greater than .90, and in some cases, they were set to a maximum of 1. With the exception of the narrow ability Memory Span (subsumed by the broad ability Short-Term Memory), differentiating between the narrow and broad abilities, at least with the current state-of-the-art psychometric measures of cognitive ability constructs, does not appear to be critical in explaining reading decoding skills.

In addition, school psychologists should consider that from the perspective of CHC theory, there are no measures available that represent broad abilities and narrow abilities in a pure manner— uncontaminated by *g*. However, those professionals using the WJ III (Woodcock et al., 2001) and other tests specifically designed to measure CHC abilities may benefit from knowing the tests that best measure the broad and narrow abilities included in this research. Across the Two-Stratum Model and Three-Stratum Model and across all age levels, with few exceptions, the WJ III Tests Sound Blending, Visual–Auditory Learning, and Visual Matching demonstrated the highest path coefficients with their respective broad and narrow abilities. Based on the Two-Stratum Model, the broad ability Crystallized Intelligence was best represented by the Tests Verbal Comprehension and General Information at different age groups. Based on the Three-Stratum Model, these two tests, with very few exceptions, best represented their respective narrow abilities (Lexical Knowledge and General Information), and the Test Oral Comprehension best represented the narrow ability Listening Ability with no exceptions. With focus on the narrow abilities subsumed by Short-Term Memory in the Three-Stratum Model, the Test Memory for Words best represented the narrow ability Memory Span.

General Intelligence

School psychologists should also not ignore *g* simply because of the frequently expressed dissatisfaction with the perceived lack of utility of global ability scores and because of the problems associated with the implementation of the IQ–achievement discrepancy approach to learning disability identification. The current study indicates that although some specific cognitive abilities are important in understanding the development of reading decoding skills, *g* remains a powerhouse general predictor and must be included in the formulation of learning-related hypothesis. Following Spearman's (1927) metaphor for describing the relations between *g* and specific cognitive abilities, *g* is the energy that powers engines whose application is specific to certain kinds of tasks, such as reading nonwords. Spearman's engines, which are built through experience and use of specific strategies during performance, are represented by the broad and narrow abilities included in this study. Although Spearman's energy— engines metaphor is likely too simple to explain fully the complexity of intelligent behavior, it does provide a plausible metaphor for explaining this study's findings of direct effects of the more specific abilities (the broad and narrow ability engines) and the indirect effects of *g* (the energy powering the engines). Based on these results, school psychologists should interpret measures of some specific cognitive abilities in reference to *g* during psychoeducational assessments designed to explain reading decoding skills.

Latent-Variable Research

Some have argued against the practical implications of findings from SEM-based research because practitioners involved in psychoeducational assessment deal with real-world, error-laden measured variables, rather than error-free latent variables (e.g., Oh, Glutting, Watkins, Youngstrom, & McDermott, 2004). We argue against this disconnect between science and practice. SEM is designed to determine the true effects of variables on each other, and we believe such true effects are just as important to practitioners as they are to scientists. If the CHC broad abilities and CHC narrow abilities indeed affect reading decoding skills, practitioners should not ignore such information, just as they should not ignore other true influences (such as direct instruction in reading decoding) on the reading skills of children, adolescence, and adults.

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