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The Cattell–Horn–Carroll Theory of Cognitive Abilities

Past, Present, and Future

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One of the most successful undertakings attributed to modern psychology is the measurement of mental abilities. Though rarely appreciated outside academe, the breakthrough in objectively gauging the nature and range of mental abilities is a pivotal development in the behavioral sciences. While this accomplishment has far-reaching implications for many areas of society, the full meaning of the test data has lacked a comprehensive theory that accounts for several major developments over the years. The track of data left by researchers remains diffuse without a clear signpost in the broad landscape of mental abilities.

—LAMB (1994, p. 386)

Since the beginning of our existence, humans have searched for order in their world. Today classification is thought of as essential to all scientific work (Dunn & Everitt, 1982). The reliable and valid classification of entities, and research regarding these entities and newly proposed entities, requires a "guide" or taxonomy (Bailey, 1994; Prentky, 1996). Although Lamb's (1994) lament about the lack of a clear signpost in the broad landscape of mental abilities had been true for decades, the crystallization of an empirically based psychometric taxonomy of human cognitive abilities finally occurred in the late 1980s to early 1990s.

In a chapter (McGrew, 1997) for the first edition of this volume, I predicted that progress in intelligence testing was being, and would continue to be energized, as a result of the articulation of this new consensus taxonomy of human cognitive abilities. The detailed description and articulation of the psychometric "table of human cognitive elements" in John "Jack" Carroll's (1993) *Human Cognitive Abilities: A Survey of Factor-Analytic Studies*, which concluded that the Cattell–Horn Gf-Gc theory was the most empirically grounded available psychometric theory of intelligence, resulted in my recommending that "all scholars, test developers, and users of intelligence tests need to become familiar with Carroll's treatise on the factors of human abilities" (McGrew, 1997, p. 151). I further suggested that practitioners heed Carroll's suggestion to "use his 'map' of known cognitive abilities to guide their selection and interpretation of tests in intelligence batteries" (p. 151). It was the purpose of that chapter to contribute, albeit in a small way, to the building of "a 'bridge' between the theoretical and empirical research on the factors of intelligence and the development and interpretation of psychoeducational assessment batteries" (p. 151).

This current chapter continues to focus on the construction of a theory-to-practice bridge, one grounded in the *Cattell–Horn–Carroll* (CHC) theory of cognitive abilities. The primary goals of this chapter are to (1) describe the evolution of contemporary CHC theory; (2) describe the broad and narrow CHC abilities; and (3) review structural evidence that supports the broad strokes of CHC theory.

THE EVOLUTION OF THE CHC THEORY OF COGNITIVE ABILITIES

Although various theories attempt to explain intelligent human behavior (Sternberg & Kaufman, 1998), "the most influential approach, and the one that has generated the most influential research, is based on psychometric testing" (Neisser et al., 1996, p. 95). The CHC theory of intelligence is the tent that houses the two most prominent psychometric theoretical models of human cognitive abilities (Daniel, 1997, 2000; Snow, 1998; Sternberg & Kaufman, 1998). CHC theory represents the integration of the Cattell–Horn Gf-Gc theory (Horn & Noll, 1977; see also Horn & Blankson, Chapter 3, this volume) and Carroll's three-stratum theory (Carroll, 1993, and Chapter 4, this volume). CHC is a psychometric theory, since it is primarily based on procedures assuming that "the structure of intelligence can be discovered by analyzing the interrelationship of scores on mental ability tests. To develop these models, large numbers of people are given many types of mental problems. The statistical technique of factor analysis is then applied to the test scores to identify the 'factors' or latent sources of individual differences in intelligence" (Davidson & Downing, 2000, p. 37).

The psychometric study of cognitive abilities is more than the exploratory factor analysis (EFA) of a set of cognitive variables. Contemporary psychometric approaches differ from traditional psychometric approaches in three major ways: (1) There is greater use of confirmatory factor analysis (CFA) as opposed to EFA; (2) the structural analysis of items is now as important as the structural analysis of variables; and (3) item response theory models now play a pivotal role (Embretson & McCollam, 2000). Space limitations necessitate a focus only on the factor-analytic portions of the contemporary psychometric approach. It is also important to recognize that non-factor-analytic research, in the form of heritability, neurocognitive, developmental, and outcome prediction (occupational and educational) studies, provides additional sources of validity evidence for CHC theory (Horn, 1998; Horn & Noll, 1997).

Early Psychometric Heritage

Historical accounts of the evolution of the psychometric approach abound (e.g., see Brody, 2000; Carroll, 1993; Horn & Noll, 1997). Prior to 1930, the usual distinction made in cognitive abilities was between verbal and quantitative abilities (Corno et al., 2002). Key early historical developments that ultimately led to the emergence of CHC theory are listed in the first two sections of Table 8.1. The lack of a detailed treatment (in this chapter) of all the developments in Table 8.1 is a necessary constraint and in no way diminishes the importance of each contribution. In addition, the major steps that led to current CHC theory are illustrated in Figure 8.1. In the next section, CHC theory is described as it evolved through a series of major theory-to-practice bridging events that occurred during the past two decades. The goal is to establish an appropriate historical record of the events that transpired and the roles that different individuals played in this process.

McGrew, Werder, & Woodcock, 1991; Woodcock, 1994; see section E1 in Table 8.1).

As illustrated in Figure 8.1, the Cattell–Horn Gf-Gc theory has its roots in Thurstone's (1938, 1947) theory of *primary mental abilities* (PMAs). In fact, according to Horn and Noll (1997), "to a considerable extent, modern hierarchical theories derive from this theory" (p. 62). At the time, Thurstone's PMA theory was at variance with the prevailing view that a higher-order *g* factor existed, and instead posited between seven and nine independent (orthogonal) PMAs: *induction* (I), *deduction* (D), *verbal comprehension* (V), *associative memory* (Ma), *spatial relations* (S), *perceptual speed* (P), *numerical facility* (N), and *word fluency* (Fw).[2] A large number of replication and extension studies confirmed Thurstone's PMAs and led to the eventual identification of over 60 abilities (Carroll, 1993; Horn & Noll, 1997; Jensen, 1998). Early pre-Carroll (1993) factor-analytic syntheses and summaries were published (Ekstrom, French, & Harman, 1979; French, 1951; French, Ekstrom, & Price, 1963; Guilford, 1967; Hakstian & Cattell, 1974; Horn, 1972) with the patterns of intercorrelations of the PMAs providing the rational for the specification of the higher-order broad *G* abilities in the Cattell–Horn Gf-Gc model (Horn & Noll, 1997; Horn & Masunaga, 2000). A thorough treatment of the contemporary Horn–Cattell Gf-Gc model can be found elsewhere in this volume (see Horn & Blankson, Chapter 3).

The "Fortuitous" Horn–Carroll–Woodcock Meeting

In the fall of 1985, I was engaged as a consultant and revision team member for the Woodcock–Johnson—Revised (WJ-R; Woodcock & Johnson, 1989). The first order of business was to attend a March 1986 "kickoff" revision meeting in Dallas, Texas. Woodcock invited a number of consultants, the two most noteworthy being John Horn and Carl Haywood. Revision team members were notified that it was important to hear Horn describe Gf-Gc theory, and also to determine whether "dynamic" testing concepts could be incorporated in the WJ-R.[3] At the last minute, the president of the publisher of the WJ (Developmental Learning Materials), Andy Bingham, made a fortuitous unilateral decision to invite (to the March 1986 WJ-R meeting) an educational psychologist he had worked with on the *American Heritage Word Frequency Book* (Carroll, Davies, & Richman, 1971). This educational psychologist, whom few members of the WJ-R revision team or the publisher's staff knew, was John B. Carroll.

The first portion of the meeting was largely devoted to a presentation of the broad strokes of Gf-Gc theory by Horn. With the exception of Carroll and Woodcock, most individuals present (myself included) were confused and struggling to grapple with the new language of "Gf this . . . Gc that . . . SAR . . . TSR . . . etc." During most of this time John Carroll sat quietly to my immediate left.

When asked for his input, Carroll pulled an old and battered square-cornered brown leather briefcase from his side, placed it on the table, and proceeded to remove a thick computer printout (of the old green and white barred tractor-feed variety associated with mainframe printers). Carroll proceeded to present the results of a just-completed Schmid–Leiman EFA of the correlation matrices from the 1977 WJ technical manual. A collective "Ah ha!" engulfed the room as Carroll's WJ factor interpretation provided a meaningful link between the theoretical terminology of Horn and the concrete world of WJ tests.

It is my personal opinion that this moment—a moment where the interests and wisdom of a leading applied test developer (Woodcock), the leading proponent of Cattell–Horn Gf-Gc theory (Horn), and one of the preeminent educational psychologists and scholars of the factor analysis of human abilities (Carroll) intersected (see section C in Table 8.1)—was the flash point that resulted in *all* subsequent theory-to-practice bridging events leading to today's CHC theory and related assessment developments. A fortuitous set of events had resulted in the psychometric stars' aligning themselves in perfect position to lead the way for every subsequent CHC assessment-related development.[4]

Publication of the Horn–Cattell Organized WJ-R Battery (1989)

With a Cattell–Horn Gf-Gc map in hand, I was directed to organize the available WJ factor- and cluster-analytic research studies (Kaufman & O'Neal, 1988; McGrew, 1986, 1987; McGue, Shinn, & Ysseldyke, 1979, 1982; Rosso & Phelps, 1988; Woodcock, 1978). Pivotal to this search for WJ Gf-Gc structure were factor analyses of the WJ correlation matrices by Carroll (personal communication, March 1986) and a WJ-based doctoral dissertation (Butler, 1987) directed by Horn. Woodcock and I, both freshly armed with rudimentary CFA skills and software, threw ourselves into reanalyses of the WJ correlation matrices. The result of this synthesis was the development of the WJ-R test development blueprint table (McGrew et al., 1991; Schrank et al., 2002), which identified existing WJ tests that were good measures of specific Gf-Gc abilities, as well as suggesting Gf-Gc "holes" that needed to be filled by creating new tests. The goal was for the WJ-R to have at least two or more cognitive tests measuring aspects of each of seven (Gf, Gc, Gv, Ga, Gsm, Glr, Gs) Cattell–Horn Gf-Gc broad abilities.

The publication of the WJ-R Tests of Cognitive Abilities (COG) represented the official "crossing over" of Gf-Gc theory from the domain of intelligence scholars and theoreticians to that of applied practitioners, particularly those conducting assessments in educational settings (see section C2 in Table 8.1). The WJ-R represented the first individually administered, nationally normed, clinical battery to close the gap between contemporary psychometric theory (i.e., Cattell–Horn Gf-Gc theory) and applied practice. According to Daniel (1997), the WJ-R was "the most thorough implementation of the multifactor model" (p. 1039) of intelligence. An important WJ-R component was the inclusion of a chapter by Horn (1991) in an appendix to the WJ-R technical manual (McGrew et al., 1991). Horn's chapter represented the first up-to-date comprehensive description of the Horn–Cattell Gf-Gc theory in a publication readily accessible to assessment practitioners. As a direct result of the publication of the WJ-R, "Gf-Gc as a second-language" emerged vigorously in educational and school psychology training programs, journal articles, books, and psychological reports, and it became a frequent topic on certain professional and assessment-related electronic listservs.

The Birth of "Battery-Free" Gf-Gc Assessment

In 1990, Woodcock published an article that, in a sense, provided a "battery-free" approach to Gf-Gc theoretical interpretation of all intelligence test batteries. In a seminal article summarizing his analysis of a series of joint CFA studies of the major intelligence batteries (i.e., the Kaufman Assessment Battery for Children [K-ABC], the Stanford–Binet Intelligence Scale: Fourth Edition [SB-IV], the Wechsler scales, the WJ, and the WJ-R; see section C3 in Table 8.1), Woodcock (1990), using empirical criteria, classified the individual tests of all the major batteries according to the Cattell–Horn Gf-Gc model.[5] For example, the WJ-R Visual–Auditory Learning test was classified by Woodcock as a strong measure of Glr, based on a median factor loading of .697 across 14 different analyses. Another example of a clear classification was the SB-IV Vocabulary test as a strong measure of Gc, based on a median factor loading of .810 across four analyses.

In the discussion of his results, Woodcock demonstrated how each individual test from each intelligence battery mapped onto the Cattell–Horn Gf-Gc taxonomy. The resulting tables demonstrated how each battery adequately measured certain Gf-Gc domains, but failed to measure, or measured poorly, other Gf-Gc domains.[6] More importantly, Woodcock (1990) suggested that in order to measure a greater breadth of Gf-Gc abilities, users of other instruments should use "cross-battery" methods to fill their respective Gf-Gc measurement voids. The concept of Gf-Gc *cross-battery assessment* was born, as well as a means to evaluate the cross-battery equivalence of scores from different batteries (Daniel, 1997).

In a sense, Woodcock had hatched the idea of Gf-Gc "battery-free" assessment, in which a common Gf-Gc assessment and interpretive taxonomy were deployed across intelligence batteries. Practitioners were no longer constrained to the interpretive structure provided by a specific intelligence battery.[7] Practitioners were given permission and a rationale to "think outside their test kits" in order to conduct more valid assessments. Based on Woodcock's (1990) findings, I (McGrew, 1993) subsequently described a Kaufman-like Gf-Gc supplemental testing approach for use with the WJ-R. Unwittingly, this was a clinical attempt to implement an informal cross-battery approach to assessment (see section C5 in Table 8.1). The development of the formal CHC cross-battery assessment approach was waiting in the wings, and blossomed during the next set of major CHC theory-to-practice bridging events.

Carroll's 1993 Principia: Human Cognitive Abilities

Carroll's 1993 book, *Human Cognitive Abilities: A Survey of Factor-Analytic Studies*, may represent in the field of applied psychometrics a work similar in stature to other so-called "principia" publications in other fields (e.g., Newton's three-volume *The Mathematical Principles of Natural Philosophy*, or *Principia* as it became known; Whitehead & Russell's *Principia Mathematica*; see section D in Table 8.1). Briefly, Carroll summarized a review and reanalysis of more than 460 different datasets that included nearly all the more important and classic factor-analytic studies of human cognitive abilities.

I am not alone in the elevation of Carroll's work to such a high stature. On the book cover, Richard Snow stated that "John Carroll has done a magnificent thing. He has reviewed and reanalyzed the world's literature on individual differences in cognitive abilities . . . no one else could have done it . . . it defines the taxonomy of cognitive differential psychology for many years to come." Burns (1994) was similarly impressed when he stated that Carroll's book "is simply the finest work of research and scholarship I have read and is destined to be *the classic study and reference work* on human abilities for decades to come" (p. 35; original emphasis). Horn (1998) described Carroll's (1993) work as a "tour de force summary and integration" that is the "definitive foundation for current theory" (p. 58); he also compared Carroll's summary to "Mendelyev's first presentation of a periodic table of elements in chemistry" (p. 58). Jensen (2004) stated that "on my first reading this tome, in 1993, I was reminded of the conductor Hans von Bülow's exclamation on first reading the full orchestral score of Wagner's *Die Meistersinger*, 'It's impossible, but there it is!' " (p. 4). Finally, according to Jensen,

> Carroll's magnum opus thus distills and synthesizes the results of a century of factor analyses of mental tests. It is virtually the grand finale of the era of psychometric *description and taxonomy* of human cognitive abilities. It is unlikely that his monumental feat will ever be attempted again by anyone, or that it could be much improved on. It will long be the key reference point and a solid foundation for the *explanatory* era of differential psychology that we now see burgeoning in genetics and the brain sciences. (p. 5; original emphasis)

The raw material reviewed and analyzed by Carroll was drawn from decades of tireless research by a diverse array of dedicated scholars (e.g., Spearman, Burt, Cattell, Gustaffson, Horn, Thurstone, Guilford, etc.). Carroll (1993) recognized that his theoretical model built on the research of others, particularly Cattell and Horn. According to Carroll, the Horn–Cattell Gf-Gc model "appears to offer the most well-founded and reasonable approach to an acceptable theory of the structure of cognitive abilities" (p. 62).

The beauty of Carroll's book was that for the first time ever, an empirically based taxonomy of human cognitive ability elements, based on the analysis (with a common method) of the extant literature since Spearman, was presented in a single, coherent, organized, systematic framework. Lubinski (2000) put a similar spin on the nature and importance of Carroll's principia when he stated that "Carroll's (1993) three-stratum theory is, in many respects, not new. Embryonic outlines are seen in earlier psychometric work (Burt, Cattell, Guttman, Humphreys, and Vernon, among others). But the empirical bases for Carroll's (1993) conclusions are unparalleled; readers should consult this source for a systematic detailing of more molecular abilities" (p. 412).

Carroll proposed a three-tier model of human cognitive abilities that differentiates abilities as a function of breadth. At the broadest level (stratum III) is a general intelligence factor, conceptually similar to Spearman's and Vernon's *g*. Next in breadth are eight broad abilities that represent "basic constitutional and long-standing characteristics of individuals that can govern or influence a great variety of behaviors in a given domain" (Carroll, 1993, p. 634). Stratum II includes the abilities of *fluid intelligence* (Gf), *crystallized intelligence* (Gc), *general memory and learning* (Gy), *broad visual perception* (Gv), *broad auditory perception* (Ga), *broad retrieval ability* (Gr), *broad cognitive speediness* (Gs), and *reaction time/decision speed* (Gt). Finally, stratum level I includes numerous narrow abilities that are subsumed by the stratum II abilities, which in turn are subsumed by the single stratum III *g* factor. Carroll's chapter in this volume (see Chapter 4) provides a more detailed summary of his model.

It is important to note that the typical schematic representation of Carroll's three-stratum model does not precisely mirror the operational structure generated by his EFA with the Schmid–Leiman orthogonalization procedure (EFA-SL). The typical depiction of Carroll's model looks much like the CHC theory model (Figure 8.1e). In reality, assuming a three-order (three-stratum) factor solution, Carroll's analyses looked more like Figure 8.1d, where the following elements are presented: (1) All tests' loading on the third-order *g* factor (arrows from *g* to T1–T12; omitted from figure); (2) salient loadings for tests on their respective first-order factor(s) (e.g., arrows from PMA1 to T1–T3); (3) salient loadings for tests on their respective second-order factor(s) (e.g., arrows from G_1 to T1–T6); (4) first-order factors' loading on their respective second-order factor(s) (e.g., arrows from G_1 to PMA1 and PMA2); and (5) second-order factors' loading on the third-order *g* factor (e.g., arrows from G_1 and G_2 to *g*).[8]

In a sense, Carroll provided the field of intelligence the much-needed "Rosetta stone" that would serve as a key for deciphering and organizing the enormous mass of human cognitive abilities structural literature that had accumulated since the days of Spearman. Carroll's work was also influential in creating the awareness among intelligence scholars, applied psychometricians, and assessment professionals, that understanding human cognitive abilities required three-stratum vision. As a practical benefit, Carroll's work provided a common nomenclature for professional communication—a nomenclature that would go "far in helping us all better understand what we are measuring, facilitate better communication between and among professionals and scholars, and increase our ability to compare individual tests across and within intelligence batteries" (McGrew, 1997, p. 171).

The importance of the convergence on a provisional cognitive ability structural framework should not be minimized. Such a structure, grounded in a large body of convergent and discriminant validity research, is the first of at least a dozen conditions required for the building of an aptitude theory that can, in turn, produce a theory of aptitude–treatment interactions (Snow, 1998, p. 99).

CHC (Gf-Gc) Investigations, Integrations, and Extensions

The "CIA Book"

The collective influence of the Cattell–Horn Gf-Gc theory, Carroll's (1993) treatise, and the publication of the Cattell–Horn Gf-Gc-based WJ-R was reflected in the fact that nine chapters were either devoted to, or included significant treatment of, the Cattell–Horn Gf-Gc and/or Carroll three-stratum theories in Flanagan, Genshaft, and Harrison's (1997) edited volume *Contemporary Intellectual Assessment: Theories, Tests, and Issues* (often referred to as the "CIA book"). In turn, this publication was also a major theory-to-practice bridging event (see section E3 in Table 8.1), for three reasons.

First, the CIA book was the first one intended for university trainers and assessment practitioners that included chapters describing both the Cattell–Horn and Carroll models by the theorists themselves (Horn and Carroll). For those unfamiliar with the Horn Gf-Gc theory chapter in the WJ-R technical manual (McGrew et al., 1991), the CIA book provided a long-overdue introduction of the "state of the art" of contemporary psychometric theories of intelligence to the professional keepers of the tools of the intelligence-testing trade (e.g., school psychologists).

Second, Flanagan and I, while digesting

the implication of the need for three-stratum vision (as articulated by Carroll) and collaborating on a WJ-R–Kaufman Adolescent and Adult Intelligence Test (KAIT) cross-battery CFA study (see Flanagan & McGrew, 1998), realized that the prior Gf-Gc test classifications (Woodcock, 1990) described tests only at the broad-ability or stratum II level, and they needed to be "taken down to the next level"—to stratum I or the narrow-ability level.[9] In order to do so, a single taxonomy was needed. Neither the Cattell–Horn nor the Carroll model was picked over the other; instead, a "synthesized Carroll and Horn–Cattell Gf-Gc framework" (McGrew, 1997, p. 152) was developed, based on both Horn and Carroll's writings and a review of a previously unpublished EFA-SL of the WJ-R completed by Carroll (see section F1 in Table 8.1).

Finally, included in the CIA book was the first formal description of the assumptions, foundations, and operationalized set of principles for Gf-Gc cross-battery assessment (Flanagan & McGrew, 1997; see section F2 in Table 8.1). The cross-battery seed planted by Woodcock (1990) had given birth. The subsequent spreading of the assessment gospel as per Gf-Gc cross-battery (Flanagan & McGrew, 1997; Flanagan, McGrew, & Ortiz, 2000; Flanagan & Ortiz, 2001; Flanagan, Ortiz, Alfonso, & Mascolo, 2002; McGrew & Flanagan, 1998; see sections F4–F6 in Table 8.1) infused Gf-Gc theory into the minds of assessment practitioners and university training programs, regardless of their choice of favorite intelligence battery (e.g., the Cognitive Assessment System [CAS], the Differential Ability Scales [DAS], the K-ABC, the SB-IV, or the Wechsler Intelligence Scale for Children—Third Edition [WISC-III]). The formalization of Gf-Gc cross-battery assessment, primarily as the result of the work of Flanagan, was another significant theory-to-practice bridging event. Daniel (1997) described the cross-battery approach as "intriguing" and "creative work now being done to integrate and interpret all cognitive batteries within the framework of a single multifactor model" (p. 1043).

Gf-Gc cross-battery assessment did not discriminate among test kits on the basis of test name, heritage, publisher, type or color of carrying case, prominent authors (dead or alive), or presence or absence of manipulatives or a performance scale. The cumulative impact of the introduction of Gf-Gc cross-battery assessment, following on the heels of the 1989 publication of the Gf-Gc organized WJ-R and Carroll's 1993 principia, established a Gf-Gc theory foothold in the field of applied intelligence testing. The intelligence theory-to-practice gap had narrowed fast. The CHC "tipping point" had been reached.[10]

CHC: The Rest of the Story

The first published record of the linking of Cattell–Horn–Carroll is in Flanagan and colleagues (2000), where it was stated that "a first effort to create a single Gf-Gc taxonomy for use in the evaluation and interpretation of intelligence batteries was the integrated Cattell–Horn–Carroll model (McGrew, 1997)" (p. 28).

The derivation of the name *Cattell–Horn–Carroll* (CHC) theory remains a mystery to many. To the best of my knowledge, the first formal published definition of CHC theory was presented in the WJ III technical manual (McGrew & Woodcock, 2001; see section F5 in Table 8.1):

> Cattell–Horn–Carroll theory of cognitive abilities. An amalgamation of two similar theories about the content and structure of human cognitive abilities (J. B. Carroll & J. L. Horn, personal communication, July 1999). The first of these two theories is Gf-Gc theory (Cattell, 1941; Horn, 1965) and the second is Carroll's (1993) three-stratum theory. CHC taxonomy is the most comprehensive and empirically supported framework available for understanding the structure of human cognitive abilities. (p. 9)

Despite the foothold Gf-Gc theory had achieved in the field of applied intelligence testing prior to 1999, the term "Gf-Gc" was often met with puzzled looks by recipients of psychological reports, sounded esoteric and nonmeaningful, and continued unintentionally to convey the inaccurate belief that the theory was a two-factor model (Gf and Gc), despite the fact that it had evolved to a model of eight or nine broad abilities. Having dealt with this communication problem since the publication of the WJ-R in 1989, Woodcock, together with the author of the Stanford–Binet Intelligence Scales, Fifth Edition (SB5; Roid, 2003) and staff members

from Riverside Publishing, met with Horn and Carroll privately in Chapel Hill, North Carolina, to seek a common, more meaningful umbrella term that would recognize the strong structural similarities of their respective theoretical models, yet also recognize their differences. This sequence of conversations resulted in a verbal agreement that the phrase "Cattell–Horn–Carroll theory of cognitive abilities" made significant practical sense, and appropriately recognized the historical order of scholarly contribution of the three primary contributors (see section E4 in Table 8.1). That was it. The term *CHC theory* emerged from private personal communications in July 1999, and seeped into subsequent publications.[11]

CHC theory represents *both* the Cattell–Horn and Carroll models, in their respective splendor. Much like the phrase "information-processing theories or models," which provides an overarching theoretical umbrella for a spectrum of very similar (yet different) theoretical model variations (Lohman, 2001), CHC theory serves the same function for the "variations on a Gf-Gc theme" by Cattell–Horn and Carroll, respectively. Table 8.2 compares and contrasts the major similarities and differences between the Cattell–Horn Gf-Gc and Carroll three-stratum models. As described above, the CHC model (Figure 8.1e) used extensively in applied psychometrics and intelligence testing during the past decade is a consensus model. The specific organization and definitions of broad and narrow CHC abilities are summarized in Table 8.3.

In the next section, a review of the CHC-related structural factor-analytic research published during the past decade is presented.[12] The purpose of this review is to help the field iterate toward a more complete and better understanding of the structure of human cognitive abilities.

EMPIRICAL EVALUATIONS OF THE "COMPLETE" CHC MODEL

An acknowledged limitation of Carroll's (1993, p. 579) three-stratum model was the fact that his inferences regarding the relations between different factors at different levels (strata) emerged from data derived from a diverse array of studies and samples. None of Carroll's datasets included the necessary breadth of variables to evaluate, in a single analysis, the general structure of his proposed three-stratum model. The sample sizes of most studies reviewed by Carroll were modest (median n = 198) and were limited in the breadth of variables analyzed (median number of variables = 19.6) (Roberts, Pallier, & Nelson-Goff, 1999). Some domains were weakly represented (e.g., Ga). According to Roberts and colleagues (1999), "no investigator has used [CFA] techniques to determine whether there is empirical support for the structure comprising the most salient aspects (i.e., Strata I and II) of Carroll's (1993) model" (p. 344).

This past decade has witnessed a number of EFA and/or CFA investigations that have included a wider range of CHC construct indicators. Collectively, these studies provide an opportunity to evaluate and validate the broad strokes of the CHC model (see Figure 8.1e and Table 8.3). Other studies, although not specifically designed to evaluate the CHC model, when viewed through a CHC lens provide additional support for major portions of the CHC model. The factor-analytic studies reviewed next were either (1) designed as per the CHC framework, (2) designed as per the Carroll and/or Cattell–Horn Gf-Gc models, and/or (3) were non-CHC studies that are now interpreted here through a post hoc CHC lens. Collectively, these studies provide empirical support for the broad strokes of contemporary CHC theory.

Large-Sample Studies

Studies with CHC-Designed Batteries

The most thorough evaluations of the structure of CHC theory are factor-analytic studies of variables from standardized test batteries administered to large, nationally representative samples. The most comprehensive evaluation of Carroll's three-stratum CHC model is the hierarchical cross-age (ages 6 through 90 years) multiple-group CFA of the WJ-R norm data by Bickley, Keith, and Wolfe (1995). Consistent with Carroll's (1993) conclusion that the structure of cognitive abilities is largely the same across ages, Bickley and colleagues found that the structure of cognitive abilities, as de-

TABLE 8.2. Comparison of Cattell–Horn and Carroll Theories of Human Cognitive Abilities

Cattell–Horn Gf-Gc theory	Carroll three-stratum theory	Salient similarities and differences
General intelligence (*g*)		
No	Yes	*g* (Carroll) vs. non-*g* (Cattell–Horn).
Broad abilities		
Fluid reasoning (Gf)	Fluid intelligence (Gf)	Similar.
Acculturation knowledge (Gc)	Crystallized intelligence (Gc)	Similar, with the exception that Carroll (1993 and Chapter 4, this volume) included reading and writing as narrow abilities under Gc. Horn (Horn & Noll, 1997; Horn & Masunaga, 2000) does not include reading and writing under Gc. Horn (1988) previously suggested a possible broad "language use" ability separate from Gc. Carroll (2003) subsequently noted a similar "language" factor in need of further research.
Short-term apprehension and retrieval abilities (SAR)	General memory and learning (Gy)	Carroll (1993) defined Gy as a broad ability that involves learning and memory abilities. Gy includes short-term memory span and other intermediate- to long-term memory abilities (e.g., associative, meaningful, and free-recall memory). Carroll indicated that "present evidence is not sufficient to permit a clear specification of the structure of learning and memory abilities" (p. 625). In contrast, Horn's *SAR* is more narrowly defined by short-term and working memory abilities (Horn & Noll, 1997; Horn & Masunaga, 2000). Horn includes intermediate and long-term associative and retrieval abilities under TSR/Glm.
Visual processing (Gv)	Broad visual perception (Gv)	Similar.
Auditory processing (Ga)	Broad auditory perception (Ga)	Similar.
Tertiary storage and retrieval (TSR/Glm)	Broad retrieval ability (Gr)	Carroll (1993) defined this domain primarily as the ready retrieval (fluency) and production of concepts or ideas from long-term memory (idea production). Horn also includes the same fluency of retrieval abilities, but adds a second category of abilities that involve the fluency of association in retrieval from storage over *intermediate* periods of time (minutes to hours). Carroll (1993 and Chapter 4, this volume) included these later abilities (e.g., associative memory) under Gy.
Processing speed (Gs)	Broad cognitive speediness (Gs)	Similar.
Correct decision speed (CDS)	Processing speed (RT decision speed) (Gt)	Horn's CDS (Horn & Mansunaga, 2000) appears to be defined as a more narrow ability (quickness in providing correct or incorrect answers to nontrivial tasks). Carroll's (1993) definition appears slightly broader (decision or reaction time as measured by reaction time paradigms).
Quantitative knowledge (Gq)		Horn (Horn & Noll, 1997; Horn & Masunaga, 2000) recognizes Gq as the understanding and application of math skills and concepts. Carroll (1993) reported separate narrow (stratum I) math achievement and knowledge abilities in a chapter on "Abilities in the Domain of Knowledge and Achievement." Carroll (2003) subsequently reported and acknowledged a Gq (Mathematics) factor.

Note. Complete, up-to-date definitions for each broad ability, plus narrow abilities under each broad ability, are presented in Table 8.3.

TABLE 8.3. Broad (Stratum II) and Narrow (Stratum I) CHC Ability Definitions

Fluid intelligence/reasoning (Gf): The use of deliberate and controlled mental operations to solve novel, "on-the-spot" problems (i.e., tasks that cannot be performed automatically). Mental operations often include drawing inferences, concept formation, classification, generating and testing hypotheses, identifying relations, comprehending implications, problem solving, extrapolating, and transforming information. Inductive reasoning (inference of a generalized conclusion from particular instances) and deductive reasoning (the deriving of a conclusion by reasoning; specifically, inference in which the conclusion about particulars follows necessarily from general or universal premises) are generally considered the hallmark indicators of Gf. Gf has been linked to *cognitive complexity*, which can be defined as a greater use of a wide and diverse array of elementary cognitive processes during performance.

General sequential (deductive) reasoning (RG): Ability to start with stated assertions (rules, premises, or conditions) and to engage in one or more steps leading to a solution to a problem. The processes are deductive as evidenced in the ability to reason and draw conclusions from given general conditions or premises to the specific. Often known as *hypothetico-deductive reasoning*.

Induction (I): Ability to discover the underlying characteristic (e.g., rule, concept, principle, process, trend, class membership) that underlies a specific problem or a set of observations, or to apply a previously learned rule to the problem. Reasoning from specific cases or observations to general rules or broad generalizations. Often requires the ability to combine separate pieces of information in the formation of inferences, rules, hypotheses, or conclusions.

Quantitative reasoning (RQ): Ability to inductively (I) and/or deductively (RG) reason with concepts involving mathematical relations and properties.

Piagetian reasoning (RP): Ability to demonstrate the acquisition and application (in the form of logical thinking) of cognitive concepts as defined by Piaget's developmental cognitive theory. These concepts include *seriation* (organizing material into an orderly series that facilitates understanding of relationships between events), *conservation* (awareness that physical quantities do not change in amount when altered in appearance), *classification* (ability to organize materials that possess similar characteristics into categories), etc.

Speed of reasoning (RE): Speed or fluency in performing reasoning tasks (e.g., quickness in generating as many possible rules, solutions, etc., to a problem) in a limited time. Also listed under Gs.

Crystallized intelligence/knowledge (Gc): "Can be thought of as the intelligence of the culture that is incorporated by individuals through a process of acculturation" (Horn, 1994, p. 443). Gc is typically described as a person's wealth (breadth and depth) of acquired knowledge of the language, information and concepts of specific a culture, and/or the application of this knowledge. Gc is primarily a store of verbal or language-based declarative (knowing "what") and procedural (knowing "how") knowledge, acquired through the "investment" of other abilities during formal and informal educational and general life experiences.

Language development (LD): General development or understanding and application of words, sentences, and paragraphs (not requiring reading) in spoken native-language skills to express or communicate a thought or feeling.

Lexical knowledge (VL): Extent of vocabulary (nouns, verbs, or adjectives) that can be understood in terms of correct word (semantic) meanings. Although evidence indicates that vocabulary knowledge is a separable component from LD, it is often difficult to disentangle these two highly correlated abilities in research studies.

Listening ability (LS): Ability to listen and understand the meaning of oral communications (spoken words, phrases, sentences, and paragraphs). The ability to receive and understand spoken information.

General (verbal) information (K0): Range of general stored knowledge (primarily verbal).

Information about culture (K2): Range of stored general cultural knowledge (e.g., music, art).

Communication ability (CM): Ability to speak in "real-life" situations (e.g., lecture, group participation) in a manner that transmits ideas, thoughts, or feelings to one or more individuals.

Oral production and fluency (OP): More specific or narrow oral communication skills than reflected by CM.

Grammatical sensitivity (MY): Knowledge or awareness of the distinctive features and structural principles of a native language that allows for the construction of words (morphology) and sentences (syntax). Not the skill in applying this knowledge.

Foreign-language proficiency (KL): Similar to LD, but for a foreign language.

Foreign-language aptitude (LA): Rate and ease of learning a new language.

(continued)

TABLE 8.3. *(continued)*

General (domain-specific) knowledge **(Gkn):** An individual's breadth and depth of acquired knowledge in specialized (demarcated) domains that typically do not represent the general universal experiences of individuals in a culture (Gc). Gkn reflects deep, specialized knowledge domains developed through intensive systematic practice and training (over an extended period of time), and the maintenance of the knowledge base through regular practice and motivated effort. The primary distinction between Gc and Gkn is the extent to which acquired knowledge is a function of the degree of cultural universality. Gc primarily reflects general knowledge accumulated via the experience of cultural universals.

Knowledge of English as a second language (KE): Degree of knowledge of English as a second language.

Knowledge of signing (KF): Knowledge of finger spelling and signing (e.g., American Sign Language) used in communication with persons with hearing impairments.

Skill in lip reading (LP): Competence in ability to understand communication from others by watching the movement of their mouths and expressions. Also known as *speech reading.*

Geography achievement (A5): Range of geography knowledge (e.g., capitals of countries).

General science information (K1): Range of stored scientific knowledge (e.g., biology, physics, engineering, mechanics, electronics).

Mechanical knowledge (MK): Knowledge about the function, terminology, and operation of ordinary tools, machines, and equipment. Since these factors were identified in research prior to the information/technology explosion, it is unknown whether this ability generalizes to the use of modern technology (e.g., faxes, computers, the Internet).

Knowledge of behavioral content (BC): Knowledge or sensitivity to nonverbal human communication/interaction systems (beyond understanding sounds and words; e.g., facial expressions and gestures) that communicate feelings, emotions, and intentions, most likely in a culturally patterned style.

Visual–spatial abilities **(Gv):** "The ability to generate, retain, retrieve, and transform well-structured visual images" (Lohman, 1994, p. 1000). The Gv domain represents a collection of different abilities emphasizing different processes involved in the generation, storage, retrieval, and transformation (e.g., mentally reversing or rotating shapes in space) of visual images. Gv abilities are measured by tasks (figural or geometric stimuli) that require the perception and transformation of visual shapes, forms, or images, and/or tasks that require maintaining spatial orientation with regard to objects that may change or move through space.

Visualization (Vz): The ability to apprehend a spatial form, object, or scene and match it with another spatial object, form, or scene with the requirement to rotate it (one or more times) in two or three dimensions. Requires the ability to mentally imagine, manipulate, or transform objects or visual patterns (without regard to speed of responding) and to "see" (predict) how they would appear under altered conditions (e.g., when parts are moved or rearranged). Differs from SR primarily by a deemphasis on fluency.

Spatial relations (SR): Ability to rapidly perceive and manipulate (mental rotation, transformations, reflection, etc.) visual patterns, or to maintain orientation with respect to objects in space. SR may require the identification of an object when viewed from different angles or positions.

Closure speed (CS): Ability to quickly identify a familiar meaningful visual object from incomplete (vague, partially obscured, disconnected) visual stimuli, without knowing in advance what the object is. The target object is assumed to be represented in the person's long-term memory store. The ability to "fill in" unseen or missing parts in a disparate perceptual field and form a single percept.

Flexibility of closure (CF): Ability to identify a visual figure or pattern embedded in a complex, distracting, or disguised visual pattern or array, when knowing in advance what the pattern is. Recognition of, yet the ability to ignore, distracting background stimuli is part of the ability.

Visual memory (MV): Ability to form and store a mental representation or image of a visual shape or configuration (typically during a brief study period), over at least a few seconds, and then to recognize or recall it later (during the test phase).

Spatial scanning (SS): Ability to quickly and accurately survey (visually explore) a wide or complicated spatial field or pattern and identify a particular configuration (path) through the visual field. Usually requires visually following the indicated route or path through the visual field.

Serial perceptual integration (PI): Ability to identify (and typically name) a pictorial or visual pattern when parts of the pattern are presented rapidly in serial order (e.g., portions of a line drawing of a dog are passed in sequence through a small "window").

Length estimation (LE): Ability to accurately estimate or compare visual lengths or distances without the aid of measurement instruments.

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TABLE 8.3. *(continued)*

Perceptual illusions (IL): The ability to resist being affected by the illusory perceptual aspects of geometric figures (i.e., not forming a mistaken perception in response to some characteristic of the stimuli). May best be thought of as a person's "response tendency" to resist perceptual illusions.

Perceptual alternations (PN): Consistency in the rate of alternating between different visual perceptions.

Imagery (IM): Ability to mentally depict (encode) and/or manipulate an object, idea, event or impression (that is not present) in the form of an abstract spatial form. Separate IM level and rate (fluency) factors have been suggested (see chapter text).

Auditory processing **(Ga):** Abilities that "depend on sound as input and on the functioning of our hearing apparatus" (Stankov, 1994, p. 157). A key characteristic of Ga abilities is the extent to which an individual can cognitively "control" (i.e., handle the competition between "signal" and "noise") the perception of auditory information (Gustafsson & Undheim, 1996), The Ga domain circumscribes a wide range of abilities involved in discriminating patterns in sounds and musical structure (often under background noise and/or distorting conditions), as well as the abilities to analyze, manipulate, comprehend, and synthesize sound elements, groups of sounds, or sound patterns. Although Ga abilities play an important role in the development of language abilities (Gc), Ga abilities do not require the comprehension of language (Gc).

Phonetic coding (PC): Ability to code, process, and be sensitive to nuances in phonemic information (speech sounds) in short-term memory. Includes the ability to identify, isolate, blend, or transform sounds of speech. Frequently referred to as *phonological* or *phonemic awareness.*

Speech sound discrimination (US): Ability to detect and discriminate differences in phonemes or speech sounds under conditions of little or no distraction or distortion.

Resistance to auditory stimulus distortion (UR): Ability to overcome the effects of distortion or distraction when listening to and understanding speech and language. It is often difficult to separate UR from US in research studies.

Memory for sound patterns (UM): Ability to retain (on a short-term basis) auditory events such as tones, tonal patterns, and voices.

General sound discrimination (U3): Ability to discriminate tones, tone patterns, or musical materials with regard to their fundamental attributes (pitch, intensity, duration, and rhythm).

Temporal tracking (UK): Ability to mentally track auditory temporal (sequential) events so as to be able to count, anticipate or rearrange them (e.g., reorder a set of musical tones). According to Stankov (2000), UK may represent the first recognition of the ability (Stankov & Horn, 1980) that is now interpreted as working memory (MW).

Musical discrimination and judgment (U1, U9): Ability to discriminate and judge tonal patterns in music with respect to melodic, harmonic, and expressive aspects (e.g., phrasing, tempo, harmonic complexity, intensity variations).

Maintaining and judging rhythm (U8): Ability to recognize and maintain a musical beat.

Sound intensity/duration discrimination (U6): Ability to discriminate sound intensities and to be sensitive to the temporal/rhythmic aspects of tonal patterns.

Sound frequency discrimination (U5): Ability to discriminate frequency attributes (pitch and timbre) of tones.

Hearing and speech threshold factors (UA, UT, UU): Ability to hear pitch and varying sound frequencies.

Absolute pitch (UP): Ability to perfectly identify the pitch of tones.

Sound localization (UL): Ability to localize heard sounds in space.

Short-term memory **(Gsm):** The ability to apprehend and maintain awareness of elements of information in the immediate situation (events that occurred in the last minute or so). A limited-capacity system that loses information quickly through the decay of memory traces, unless an individual activates other cognitive resources to maintain the information in immediate awareness.

Memory span (MS): Ability to attend to, register, and immediately recall (after only one presentation) temporally ordered elements and then reproduce the series of elements in correct order.

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TABLE 8.3. *(continued)*

Working memory (MW): Ability to temporarily store and perform a set of cognitive operations on information that requires divided attention and the management of the limited capacity resources of short-term memory. Is largely recognized to be the mind's "scratchpad" and consists of up to four subcomponents. The *phonological or articulatory loop* processes auditory–linguistic information, while the *visual–spatial sketchpad/scratchpad* is the temporary buffer for visually processed information. The *central executive mechanism* coordinates and manages the activities and processes in working memory. The component most recently added to the model is the episodic buffer. Recent research (see chapter text) suggests that MW is *not* of the same nature as the other 60+ narrow-factor-based, trait-like individual-difference constructs included in this table. MW is a theoretically developed construct (proposed to explain memory findings from experimental research) and not a label for an individual-difference-type factor. MW is retained in the current CHC taxonomy table as a reminder of the importance of this construct in understanding new learning and performance of complex cognitive tasks (see chapter text).

Long-term storage and retrieval **(Glr):** The ability to store and consolidate new information in long-term memory, and later fluently retrieve the stored information (e.g., concepts, ideas, items, names) through association. Memory consolidation and retrieval can be measured in terms of information stored for minutes, hours, weeks, or longer. Horn (Horn & Masunaga, 2000) differentiates two major types of Glr—fluency of retrieval of information over minutes or a few hours (*intermediate memory*), and fluency of association in retrieval from storage over days, months or years. Ekstrom et al. (1979) distinguished two additional characteristic processes of Glr: "(1) reproductive processes, which are concerned with retrieving stored facts, and (2) reconstructive processes, which involve the generation of material based on stored rules" (p. 24). Glr abilities have been prominent in creativity research, where they have been referred to as *idea production*, *ideational fluency*, or *associative fluency*.

Associative memory (MA): Ability to recall one part of a previously learned but unrelated pair of items (that may or may not be meaningfully linked) when the other part is presented (e.g., paired-associate learning).

Meaningful memory (MM): Ability to note, retain, and recall information (set of items or ideas) where there is a meaningful relation between the bits of information, the information comprises a meaningful story or connected discourse, or the information relates to existing contents of memory.

Free-recall memory (M6): Ability to recall (without associations) as many unrelated items as possible, in any order, after a large collection of items is presented (each item presented singly). Requires the ability to encode a "superspan collection of material" (Carroll, 1993, p. 277) that cannot be kept active in short-term or working memory.

Ideational fluency (FI): Ability to rapidly produce a series of ideas, words, or phrases related to a specific condition or object. Quantity, not quality or response originality, is emphasized. The ability to think of a large number of different responses when a given task requires the generation of numerous responses. Ability to call up ideas.

Associational fluency (FA): A highly specific ability to rapidly produce a series of words or phrases associated in meaning (semantically associated; or some other common semantic property) when given a word or concept with a restricted area of meaning. In contrast to FI, quality rather quantity of production is emphasized.

Expressional fluency (FE): Ability to rapidly think of and organize words or phrases into meaningful complex ideas under general or more specific cued conditions. Requires the production of connected discourse in contrast to the production of isolated words (e.g., FA, FW). Differs from FI in the requirement to rephrase given ideas rather than generating new ideas. The ability to produce different ways of saying much the same thing.

Naming facility (NA): Ability to rapidly produce accepted names for concepts or things when presented with the thing itself or a picture of it (or cued in some other appropriate way). The naming responses must be in an individual's long-term memory store (i.e., objects or things to be named have names that are very familiar to the individual). In contemporary reading research, this ability is called *rapid automatic naming* (RAN).

Word fluency (FW): Ability to rapidly produce isolated words that have specific phonemic, structural, or orthographic characteristics (independent of word meanings). Has been mentioned as possibly being related to the "tip-of-the-tongue" phenomenon (Carroll, 1993). One of the first fluency abilities identified (Ekstrom et al., 1979).

Figural fluency (FF): Ability to rapidly draw or sketch as many things (or elaborations) as possible when presented with a nonmeaningful visual stimulus (e.g., set of unique visual elements). Quantity is emphasized over quality or uniqueness.

Figural flexibility (FX): Ability to rapidly change set and try out a variety of approaches to solutions for figural problems that have several stated criteria. Fluency in successfully dealing with figural tasks that require a variety of approaches to a given problem.

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TABLE 8.3. *(continued)*

Sensitivity to problems (SP): Ability to rapidly think of a number of alternative solutions to practical problems (e.g., different uses of a given tool). More broadly may be considered imagining problems dealing with a function or change of function of objects and/or identifying methods to address the problems (Royce, 1973). Requires the recognition of the existence of a problem.

Originality/creativity (FO): Ability to rapidly produce unusual, original, clever, divergent, or uncommon responses (expressions, interpretations) to a given topic, situation, or task. The ability to invent unique solutions to problems or to develop innovative methods for situations where a standard operating procedure does not apply. Following a new and unique path to a solution. FO differs from FI in that FO focuses on the quality of creative responses, while FI focuses on an individual's ability to think of a large number of different responses.

Learning abilities (L1): General learning ability rate. Poorly defined by existing research.

Cognitive Processing Speed **(Gs):** The ability to automatically and fluently perform relatively easy or overlearned cognitive tasks, especially when high mental efficiency (i.e., attention and focused concentration) is required. The speed of executing relatively overlearned or automatized elementary cognitive processes.

Perceptual speed (P): Ability to rapidly and accurately search, compare (for visual similarities or differences) and identify visual elements presented side by side or separated in a visual field. Recent research (Ackerman, Beier, & Boyle, 2002; Ackerman & Cianciolo, 2000; Ackerman & Kanfer, 1993; see chapter text) suggests that P may be an *intermediate*-stratum ability (between narrow and broad) defined by four narrow subabilities:

1. *Pattern recognition (Ppr):* Ability to quickly recognize simple visual patterns.
2. *Scanning (Ps):* Ability to scan, compare, and look up visual stimuli.
3. *Memory (Pm):* Ability to perform visual-perceptual speed tasks that place significant demands on immediate short-term memory.
4. *Complex (Pc):* Ability to perform visual pattern recognition tasks that impose additional cognitive demands, such as spatial visualization, estimating and interpolating, and heightened memory span loads.

Rate of test taking (R9): Ability to rapidly perform tests that are relatively easy or overlearned (require very simple decisions). This ability is not associated with any particular type of test content or stimuli. May be similar to a higher-order *psychometric time* factor (Roberts & Stankov, 1999; Stankov, 2000). Recent research has suggested that R9 may better be classified as an *intermediate*-stratum ability (between narrow and broad) that subsumes almost all psychometric speeded measures (see chapter text).

Number facility (N): Ability to rapidly perform basic arithmetic (i.e., add, subtract, multiply, divide) and accurately manipulate numbers quickly. N does not involve understanding or organizing mathematical problems and is not a major component of mathematical/quantitative reasoning or higher mathematical skills.

Speed of reasoning (RE): Speed or fluency in performing reasoning tasks (e.g., quickness in generating as many possible rules, solutions, etc., to a problem) in a limited time. Also listed under Gf.

Reading speed (fluency) (RS): Ability to silently read and comprehend connected text (e.g., a series of short sentences, a passage) rapidly and automatically (with little conscious attention to the mechanics of reading). Also listed under Grw.

Writing speed (fluency) (WS): Ability to copy words or sentences correctly and repeatedly, or writing words, sentences, or paragraphs as quickly as possible. Also listed under Grw and Gps.

Decision/reaction time or speed **(Gt):** The ability to react and/or make decisions quickly in response to simple stimuli, typically measured by chronometric measures of reaction and inspection time. In psychometric methods, quickness in providing answers (correct or incorrect) to tasks of trivial difficulty (also known as *correct decision speed*, or CDS)—may relate to cognitive tempo.

Simple reaction time (R1): Reaction time (in milliseconds) to the onset of a single stimulus (visual or auditory) that is presented at a particular point of time. R1 is frequently divided into the phases of *decision time* (DT; the time to decide to make a response and the finger leaves a home button) and *movement time* (MT; the time to move finger from the home button to another button where the response is physically made and recorded).

Choice reaction time (R2): Reaction time (in milliseconds) to the onset of one of two or more alternative stimuli, depending on which alternative is signaled. Similar to R1, can be decomposed into DT and MT. A frequently used experimental method for measuring R2 is the Hick paradigm.

Semantic processing speed (R4): Reaction time (in milliseconds) when a decision requires some encoding and mental manipulation of the stimulus content.

Mental comparison speed (R7): Reaction time (in milliseconds) where stimuli must be compared for a particular characteristic or attribute.

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TABLE 8.3. *(continued)*

Inspection time (IT): The ability to quickly (in milliseconds) detect change or discriminate between alternatives in a very briefly displayed stimulus (e.g., two different-sized vertical lines joined horizontally across the top).

Psychomotor speed **(Gps):** The ability to rapidly and fluently perform body motor movements (movement of fingers, hands, legs, etc.), independently of cognitive control.

Speed of limb movement (R3): The ability to make rapid specific or discrete motor movements of the arms or legs (measured after the movement is initiated). Accuracy is not important.

Writing speed (fluency) (WS): Ability to copy words or sentences correctly and repeatedly, or writing words, sentences, or paragraphs as quickly as possible. Also listed under Grw and Gps.

Speed of articulation (PT): Ability to rapidly perform successive articulations with the speech musculature.

Movement time (MT): Recent research (see summaries by Deary, 2003; Nettelbeck, 2003; see chapter text) suggests that MT may be an intermediate-stratum ability (between narrow and broad strata) that represents the second phase of reaction time as measured by various elementary cognitive tasks. The time taken to physically move a body part (e.g., a finger) to make the required response is MT. MT may also measure the speed of finger, limb, or multilimb movements or vocal articulation (*diadochokinesis*; Greek for "successive movements") (Carroll, 1993; Stankov, 2000); it is also listed under Gt.

Quantitative knowledge **(Gq):** A person's wealth (breadth and depth) of acquired store of declarative and procedural quantitative knowledge. Gq is largely acquired through the "investment" of other abilities, primarily during formal educational experiences. It is important to recognize that RQ, which is the ability to reason inductively and deductively when solving quantitative problems, is not included under Gq, but rather is included in the Gf domain. Gq represents an individual's store of acquired mathematical knowledge, not reasoning with this knowledge.

Mathematical knowledge (KM): Range of general knowledge about mathematics. Not the performance of mathematical operations or the solving of math problems.

Mathematical achievement (A3): Measured (tested) mathematics achievement.

Reading/writing **(Grw):** A person's wealth (breadth and depth) of acquired store of declarative and procedural reading and writing skills and knowledge. *Grw* includes both basic skills (e.g., reading and spelling of single words) and the ability to read and write complex connected discourse (e.g., reading comprehension and the ability to write a story).

Reading decoding (RD): Ability to recognize and decode words or pseudowords in reading, using a number of subabilities (e.g., grapheme encoding, perceiving multiletter units and phonemic contrasts, etc.).

Reading comprehension (RC): Ability to attain meaning (comprehend and understand) connected discourse during reading.

Verbal (printed) language comprehension (V): General development, or the understanding of words, sentences, and paragraphs in native language, as measured by reading vocabulary and reading comprehension tests. Does not involve writing, listening to, or understanding spoken information.

Cloze ability (CZ): Ability to read and supply missing words (that have been systematically deleted) from prose passages. Correct answers can only be supplied if the person understands (comprehends) the meaning of the passage.

Spelling ability (SG): Ability to form words with the correct letters in accepted order (spelling).

Writing ability (WA): Ability to communicate information and ideas in written form so that others can understand (with clarity of thought, organization, and good sentence structure). Is a broad ability that involves a number of other writing subskills (knowledge of grammar, the meaning of words, and how to organize sentences or paragraphs).

English usage knowledge (EU): Knowledge of the "mechanics" (capitalization, punctuation, usage, and spelling) of written and spoken English-language discourse.

Reading speed (fluency) (RS): Ability to silently read and comprehend connected text (e.g., a series of short sentences, a passage) rapidly and automatically (with little conscious attention to the mechanics of reading). Also listed under Gs.

Writing speed (fluency) (WS): Ability to copy words or sentences correctly and repeatedly, or writing words, sentences, or paragraphs as quickly as possible. Also listed under Gs and Gps.

(continued)

TABLE 8.3. *(continued)*

Psychomotor abilities **(Gp):** The ability to perform body motor movements (movement of fingers, hands, legs, etc.) with precision, coordination, or strength.

Static strength (P3): The ability to exert muscular force to move (push, lift, pull) a relatively heavy or immobile object.

Multilimb coordination (P6): The ability to make quick specific or discrete motor movements of the arms or legs (measured after the movement is initiated). Accuracy is not relevant.

Finger dexterity (P2): The ability to make precisely coordinated movements of the fingers (with or without the manipulation of objects).

Manual dexterity (P1): Ability to make precisely coordinated movements of a hand, or a hand and the attached arm.

Arm–hand steadiness (P7): The ability to precisely and skillfully coordinate arm–hand positioning in space.

Control precision (P8): The ability to exert precise control over muscle movements, typically in response to environmental feedback (e.g., changes in speed or position of object being manipulated).

Aiming (AI): The ability to precisely and fluently execute a sequence of eye–hand coordination movements for positioning purposes.

Gross body equilibrium (P4): The ability to maintain the body in an upright position in space, or regain balance after balance has been disturbed.

Olfactory abilities **(Go):** Abilities that depend on sensory receptors of the main olfactory system (nasal chambers). The cognitive and perceptual aspects of this domain have not yet been widely investigated (see chapter text).

Olfactory memory (OM): Memory for odors (smells).

Olfactory sensitivity (OS): Sensitivity to different odors (smells).

Tactile abilities **(Gh):** Abilities that depend on sensory receptors of the tactile (touch) system for input and on the functioning of the tactile apparatus. The cognitive and perceptual aspects of this domain have not yet been widely investigated (see chapter text).

Tactile sensitivity (TS): The ability to detect and make fine discriminations of pressure on the surface of the skin.

Kinesthetic abilities **(Gk):** Abilities that depend on sensory receptors that detect bodily position, weight, or movement of the muscles, tendons, and joints. The cognitive and perceptual aspects of this domain have not yet been widely investigated.

Kinesthetic sensitivity (KS): The ability to detect, or be aware, of movements of the body or body parts, including the movement of upper body limbs (arms), and the ability to recognize a path the body previously explored without the aid of visual input (blindfolded).

Note. Many of the ability definitions in this table, or portions thereof, were originally published in McGrew (1997); these, in turn, were developed from a detailed reading of *Human Cognitive Abilities: A Survey of Factor-Analytic Studies* (Carroll, 1993). The two-letter narrow-ability (stratum I) factor codes (e.g., RG), as well as most of the broad-ability factor codes (e.g., Gf), are from Carroll (1993). The McGrew (1997) definitions have been revised and extended here, based on a review of a number of additional sources. Primary sources include Carroll (1993), Corsini (1999), Ekstrom et al. (1979), Fleishman and Quaintance (1984), and Sternberg (1994). An ongoing effort to refine the CHC definitions of abilities can be found in the form of the Cattell–Horn–Carroll (CHC) Definition Project (*http://www.iapsych.com/chcdef.htm*).

fined by eight broad abilities (Gf, Gv, Gs, Glr, Gc, Ga, Gsm, Gq) and a higher-order *g* ability, was invariant from childhood to late adulthood. The authors concluded that "this study provides compelling evidence that the three-stratum theory may form a parsimonious model of intelligence. The fact that it is also grounded in a strong foundation of vast, previous research also lends strong support for the acceptance of the model" (p. 323).

More recently, in the large, nationally representative WJ III standardization sample, we (McGrew & Woodcock, 2001) reported a CHC-based CFA of 50 test variables from ages 6 through late adulthood. Support was found for a model consisting of a higher-order *g* factor that subsumed the broad abilities of Gf, Gc, Gv, Ga, Gsm, Glr, Gs, Grw, and Gq. A comparison with four alternative models found the CHC model to be the most plausible representation of the structure in the data.

Subsequently, we (Taub & McGrew, 2004) used multiple-group CFAs to evaluate the factorial cross-age invariance of the WJ III COG from ages 6 through 90+. In addition to supporting the construct validity of a higher-order *g* and seven lower-order broad CHC factors (Gf, Gc, Gv, Ga, Gsm, Glr, Gs), our analyses supported the invariance of the WJ III COG measurement and CHC theoretical frameworks. These findings are consistent with those of Bickley and colleagues (1995) and provide additional support for the validity of the broad- and general-stratum abilities of CHC theory (from childhood through adulthood).

Of particular interest to the current chapter is the fact that in his last formal publication, Carroll (2003) applied his factor-analytic procedures and skills to an investigation of the structure of the 1989 WJ-R norm data. The purpose of Carroll's analyses was to compare the viability of three different views of the structure of human cognitive abilities. To paraphrase Carroll, these views can be characterized as follows:

1. *Standard multifactorial model*. This is the classic view of Spearman (Spearman, 1927, Spearman & Wynn Jones, 1950) and others (e.g., Carroll, 1993; Jensen, 1998; Thurstone & Thurstone, 1941) that a general (*g*) intelligence factor exists, as well as a variety of less general "broad" abilities.

2. *Limited structural analysis model*. This model also posits the presence of higher-order *g* ability, as well as lower-order broad abilities; however, it suggests that fluid intelligence (Gf) is highly correlated with, and may be identical with, *g*. This model is primarily associated with Gustafsson and others (Gustafsson, 1984, 1989, 2001; Gustafsson & Balke, 1993; Gustafsson & Undheim, 1996).

3. *Second-stratum multiplicity model*. This is a *g*-less model that also includes broad abilities, but suggests that the nonzero intercorrelations among lower-stratum factors do not support the existence of *g*. This is largely the view of Horn and Cattell (Cattell, 1971; Horn, 1998; Horn & Noll, 1997).

Carroll (2003) judged the WJ-R norm data to be a "sufficient" dataset for "drawing conclusions about the higher-stratum structure of cognitive abilities" (p. 8). Carroll submitted the 16- and 29-variable WJ-R correlation matrices (reported in McGrew et al., 1991) to the same EFA-SL procedures used in his 1993 survey. These EFA-based results, in turn, served as the starting point for a CFA intended to compare the three different structural model views of intelligence vis-à-vis the model comparison statistics provided by structural equation modeling (SEM) methods.[13]

Briefly, Carroll (2003) concluded that "researchers who are concerned with this structure in one way or another . . . can be assured that a general factor *g* exists, along with a series of second-order factors that measure broad special abilities" (p. 19). Carroll further stated that "doubt is cast on the view that emphasizes the importance of a Gf factor. . . . these data tend to discredit the limited structural analysis view and the second-stratum multiplicity view" (p. 17). Interestingly, in these analyses Carroll used the broad-ability nomenclature of CHC theory when reporting support for the broad abilities of Gf, Gc, Gv, Ga, Gsm, Glr, Gs, Gq, and language (composed of reading and writing tests; also known as Grw).

The most recent morphing of the long line of Stanford–Binet Intelligence Scales (the SB5; Roid, 2003) was guided extensively by the work of both Carroll and Horn (see Roid, 2003, pp. 7–11); consultation from authors of the CHC-designed WJ III (see

Roid, Woodcock, & McGrew, 1997; see also Roid, 2003, p. v); and a review of the CHC-organized cross-battery research literature of Flanagan, myself, and colleagues (see Roid, 2003, pp. 8–9). The result is a CHC-organized battery designed to measure five broad cognitive factors: Fluid Reasoning (Gf), Quantitative Reasoning (Gq), Crystallized Knowledge (Gc), Short-Term Memory (Gsm), and Visual Processing (Gv). Not measured are the broad abilities of Grw, Ga, Glr, and Gs. CFA reported in the SB5 manual indicates that the five-factor model (Gf, Gq, Gc, Gsm, Gv) was the most plausible model when compared to four alternative models (one-, two-, three-, and four-factor models).

Studies with Other Batteries

Recently, Roberts and colleagues (2000) examined the factor structure of the Armed Services Vocational Aptitude Battery (ASVAB) in terms of Gf-Gc theory and Carroll's (1993) three-stratum model. In two samples ($n = 349$, $n = 6{,}751$), adult subjects were administered both the ASVAB and marker tests from the Educational Testing Service Kit of Factor-Referenced Cognitive Tests (Ekstrom, French, Harman, & Derman, 1976). EFA and CFA supported a model that included the broad abilities of Gf, Gc, Gsm (SAR), Gv, Glr (TSR), and Gs.[14]

Although not using the language of CHC theory, Tulsky and Price's (2003) recent CFA of the Wechsler Adult Intelligence Scale—Third Edition (WAIS-III) and Wechsler Memory Scale—Third Edition (WMS-III) national standardization conorming sample also supports the CHC model. Of the six factors retained in their final cross-validated model, three factors can clearly be interpreted as broad CHC factors: Gs (Processing Speed), Gc (Verbal Comprehension), and Gv (Perceptual Organization). Tulsky and Price's Visual Memory factor could be classified as Gv (MV). The factor Tulsky and Price interpreted as Auditory Memory was defined by salient loadings from the WMS-III Logical Memory I and II, Verbal-Paired Associates I and II, and the Word List I and II tests—tests that have previously been classified according to CHC theory (see Flanagan et al., 2000) as measures of Glr (i.e., MM, MA, M6).[15] Finally, the factor defined by the WMS-III Spatial Span and WAIS-III Digit Span, Letter–Number Sequencing, and Arithmetic tests was interpreted by Tulsky and Price as Working Memory (Gsm-MW). An alternative interpretation of the Working Memory factor could be Numerical Fluency (Gs-N), due to of the common use of numerals in all tasks (e.g., Digit Span, Letter–Number Sequencing, and Arithmetic all require the manipulation of numbers; Spatial Span performance might be aided via the subvocal counting of the shapes to be recalled).

Finally, Tirre and Field's (2002) systematic investigation of the structure of the Ball Aptitude Battery (BAB), when viewed through a CHC lens, provides additional support for the broad strokes of the CHC model. These investigators reported the results of three separate cross-battery CFAs (the BAB and the Comprehensive Ability Battery; the BAB and the ASVAB; and the BAB and the General Aptitude Test Battery) and their reanalysis of the Neuman, Bolin, and Briggs (2000) BAB study. Although Tirre and Field reported 15 different types of factors across all studies, only those factors replicated in at least two of the samples are discussed here. These included *g* (General Cognitive Ability), Gps (Perceptual Motor Speed), Gs-P (Clerical Speed), Gf (Reasoning), Gc (Verbal), and Gq (Numerical Ability). Two additional Glr-type factors emerged and were defined by slightly different combinations of tests in the different analyses. What Tirre and Field labeled Episodic Memory appears to be a Glr "level" factor defined primarily by the combination of Associative Memory (MA) and Meaningful Memory (MM) measures. In contrast, their Creativity factor was defined by Glr "rate" measures requiring rapid or fluent generation of ideas (FI—Ideational Fluency). Tirre and Field interpreted an additional factor as representing "Broad Retrieval Ability." However, in two of the three investigations where this factor emerged, the strongest factor loadings were for Gf tests (BAB Inductive Reasoning, BAB Analytical Reasoning).

Small-Sample Studies

A number of small-sample studies, many of which analyzed joint (cross-battery) datasets, provide additional support for the broad strokes of CHC theory.

In a study of 179 adults, Roberts, Pallier, and Stankov (1996) used EFA with a collection of 25 cognitive measures that have been used for decades in many intelligence research studies (i.e., not a single nationally normed battery). Six CHC factors were identified. The broad factors reported included Gf, Gc, Gsm (SAR), Gv, Ga, and Gs. With the exception of a seventh separate Induction (I) factor that was correlated with Gf, the six-factor structure is consistent with CHC theory. In a study that used some of the same measures, as well as measures of tactile and kinesthetic abilities, Roberts, Stankov, Pallier, and Dolph (1997) used a combination of EFA and CFA on a set of 35 variables administered to 195 college and adult subjects. In addition to the possibility of a broad tactile–kinesthetic ability (discussed later in this chapter), this study provided support for the CHC abilities of Gc, Gf, Gv, Gsm (SAR), and a blended Gs-Gt.

Li, Jordanova, and Lindenberger (1998) also included 3 measures of tactile abilities together with 14 research tests of cognitive abilities in a study designed to explore the relations between perceptual abilities and *g* in a sample of 179 adults. Embedded in the causal model, to operationally represent *g*, were five first-order factors consistent with the CHC model: Gs (Perceptual Speed), Gf (Reasoning), and Gc (Knowledge). Two additional factors, labeled Memory and Fluency, appear to represent the "level" (MA/MM) and "rate" (FI) components of Glr when viewed through a CHC lens.

Reed and McCallum (1995) presented the results of an EFA for 104 elementary school subjects who had been administered 18 tests from the Gf-Gc-designed WJ-R and 6 tests from the Universal Nonverbal Intelligence Test (UNIT; Bracken & McCallum, 1998). The original WJ-R and UNIT correlation matrix was subsequently submitted to a CHC-designed CFA (McGrew, 1997), and the results supported a model consisting of Gf, Gv, Gs (P), Glr (MA), Gc, Ga (PC), and Gsm (MS).[16] McGhee and Liberman (1994) also used EFA methods to investigate the dimensionality of 18 measures selected from a variety of psychoeducational batteries. In a small sample of 50 second-grade students, six distinct CHC cognitive factors were identified: Gv (MV), Gsm (MS), Gv (SR), Gc, Ga (PA), and Gq (KM).[17] In addition, two tests requiring the drawing of designs represented a visual–motor factor that corresponds to abilities within Carroll's (1993) domain of broad psychomotor ability. Fifteen of the WJ-R tests were also subjected to an EFA together with 12 tests from the Detroit Tests of Learning Aptitude—Adult in a sample (n = 50) of elderly adults (Buckhalt, McGhee, & Ehrler, 2001). Buckhalt and colleagues (2001) reported evidence in support of eight CHC broad abilities (Glr, Gc, Gsm, Ga, Gq, Gf, Gv, and Gs).[18]

Cross-battery studies including tests from the KAIT (Kaufman & Kaufman, 1993) have also supported portions of the CHC model. In a sample of 255 normal adolescent and adult subjects, Kaufman, Ishikuma, and Kaufman (1994) completed an EFA of 11 tests from the WAIS-R, 8 tests from the KAIT, 2 tests from the Kaufman Functional Academic Skills Test (Kaufman & Kaufman, 1994a), and 3 tests from the Kaufman Short Neuropsychological Assessment Procedure (Kaufman & Kaufman, 1994b). Referring to their interpretation as a "Horn analysis," Kaufman and colleagues provided support for four CHC domains. Distinct Gc and Gf factors were identified. In addition, a Gsm (MS) factor was evident, which the authors labeled, in Horn's terminology, SAR. Kaufman and colleagues also presented what they termed a blended Gv-Gf factor. Inspection of the most salient tests on this blended factor (viz., WAIS-R Object Assembly, .84; Block Design, .75; Picture Completion, .61; Picture Arrangement, .61) suggests that broad Gv is a more defensible interpretation of the factor (see McGrew & Flanagan, 1998; Woodcock, 1990).

Two additional studies using the KAIT tests deserve comment. Although using a mixture of Cattell–Horn and Luria–Das terminology to interpret the factors, Kaufman's (1993) EFA of 8 KAIT and 13 K-ABC tests in a sample of 124 children ages 11–12 years supplied evidence for six CHC domains. Kaufman's KAIT and K-ABC factor results supported the validity of the Gc and Gf abilities. Kaufman's Achievement factor could be interpreted as a blend of Grw and Gq. Two different visual factors were identified and were labeled Simultaneous Processing and Broad Visualization by Kaufman. Post hoc CHC reinterpretations (see McGrew, 1997; McGrew & Flanagan, 1998) suggest that these two factors could be interpreted as broad Gv (salient loadings for K-ABC Photo Series, .80; Matrix Analogies, .61; Triangles, .61; Spatial Memory, .58; KAIT Memory for Block Designs, .32) and narrow Visual Memory (Gv-MV; KAIT Memory for Block Designs, .44, K-ABC Gestalt Closure, .42, K-ABC Hand Movements, .40) factors. Finally, the factor defined by K-ABC Number Recall and Word Order could be interpreted as Memory Span (Gsm-MS) rather than Sequential Processing.

We (Flanagan & McGrew, 1998) conducted a CHC-designed cross-battery CFA study of the KAIT tests together with select WJ-R and WISC-III tests in a nonwhite sample of 114 students in sixth, seventh, and eighth grades. Although a variety of specific hypotheses were tested at the stratum I (narrow-ability) level, support was found at the broad-factor level for the CHC abilities of Gf, Gc, Gv (MV and CS), Ga (PC), Gsm (MS), Glr (MA), Gs (P), and Grw. This study is notable in that it represented the first CHC-designed cross-battery study to attempt to evaluate, where possible in the model, all three strata of the CHC theory (see Table 8.1).

A number of recent studies have extended the CHC cross-battery research via the use of WJ III tests as CHC factor markers. In a sample of 155 elementary-school-age subjects who had been administered 18 WJ III tests and 12 tests from the Das–Naglieri CAS (Naglieri & Das, 1997), Keith, Kranzler, and Flanagan's (2001) CFA provided support for the CHC abilities of Gf, Gc, Gv, Ga (PC), Gsm, Glr (MA), and Gs. In what may be the most comprehensive CHC-organized cross-battery investigation to date we (McGrew et al., 2001) analyzed 53 different tests (26 from the WJ III, 6 from the KAIT, 11 from the WAIS-III, and 10 from the WMS-III) in a mixed university sample with and without learning disabilities (n = 200). CFAs provided support for the broad CHC abilities of Gf, Gc, Gv, Ga, Gsm, Glr, Grw, Gq, and Gs. Finally, in a more recent attempt to specify a three-stratum CHC cross-battery model, we (Phelps, McGrew, Knopik, & Ford, in press) analyzed the performance of 148 elementary-school-age students on 12 WISC-III tests and 29 WJ III tests. The best-fitting CFA model provided support for a CHC framework that included the broad abilities of Gf, Gc, Gv, Ga, Gsm, Glr, and Gs.

Empirical Evaluations: Summary and Conclusions

Collectively, the large- and small-sample structural validity studies published during the past decade support the broad strokes (i.e., the stratum II abilities) of contemporary CHC theory. The broad abilities of Gf, Gc, Gv, Ga, Gsm, Glr, Gs, Gq, and Grw have been validated in and across studies that have included a sufficient breadth of CHC indicators to draw valid conclusions. Although using the Cattell–Horn Gf-Gc theory as a guide, Stankov (2000) reached a similar conclusion (with the exception that he did not include Grw in his review).

It is likely that no single comprehensive study will ever include the necessary breadth of variables to allow for a definitive test of the complete structure of human cognitive abilities. Instead, increasingly better-designed and comprehensive studies, when viewed collectively through a CHC-organized theoretical lens, will provide for increasingly refined solutions that approximate the ideal. The research studies just reviewed, as well as contemporary reviews of recent factor-analytic research, will contribute to the ongoing search for increasingly satisfactory approximations of a psychometric model of the structure of human cognitive abilities. For example, a recent review (McGrew & Evans, 2004) of the factor-analytic research during the preceding decade (1993–2003) argues for a number of *internal* (i.e., elaboration on the nature of existing well-established broad CHC factors) and *external* (i.e., research that suggests new broad-ability domains or domains that have been only partially investigated) extensions (Stankov, 2000). CHC model extensions have focused on the broad abilities of general knowledge (Gkn), tactile abilities (Gh), kinesthetic abilities (Gk), olfactory abilities (Go), and three separate broad speed abilities (Gs, general cognitive speed; Gt, decision/reaction time or speed; and Gps, psychomotor speed).[19]

BETWIXT, BEHIND, AND BEYOND *g*

g: Betwixt Horn and Carroll

The CHC model presented in Figure 8.1e reveals a quandary for users of CHC theory—namely, "to *g* [Carroll] or not to *g* [Horn]?"

To properly evaluate the relative merits of the *g* versus no-*g* positions would require extensive reading of the voluminous *g* literature. No fewer than three books or major papers (Brand, 1996; Jensen, 1998; Nyborg, 2003) have been devoted exclusively to the topic of *g* during the past decade. The existence and nature of *g* have been debated by the giants in the field of intelligence since the days of Spearman, with no universal resolution. The essence of the Cattell–Horn versus Carroll *g* conundrum is best summarized by Hunt (1999):

> Carroll notes that abilities in the second-order stratum (e.g., Gc and Gf) are positively correlated. This led Carroll to conclude that there is a third, highest-level stratum with a single ability in it: general intelligence. Here Carroll differs with the interpretations of Cattell and Horn. Cattell and Horn acknowledge the correlation, but regard it as a statistical regularity produced because it is hard to define a human action that depends on just one of the second-order abilities. Carroll sees the same correlation as due to the causal influence of general intelligence. It is not clear to me how this controversy could be resolved. (p. 2)

Even if no such "thing" as *g* exists, applied psychologists need to be cognizant of the reality of the positive manifold among the individual tests in intelligence batteries which is practically operationalized in the form of the global composite IQ score (Daniel, 2000).[20] Also, the positive manifold among cognitive measures often must be included in research designs to test and evaluate certain hypotheses. Researchers using the CHC model must make a decision whether *g* should be included in the application of the model in research. Brief summaries of the respective Horn and Carroll positions are presented below.

Horn on *g*

Horn (see, e.g., Horn & Masunaga, 2000) typically presents two lines of evidence against the "*g* as a unitary process" position. Structurally, Horn and Masunaga (2000) argue that "batteries of tests well selected to provide reliable measures of the various processes thought to be indicative of general intelligence do not fit the one common factor (i.e., Spearman *g*) model. This has been demonstrated time and time again" (p. 139). The statement also challenges Jensen's (1984, 1993) *g* argument in the form of the "indifference of the indicator" (see Horn, 1998). Horn (e.g., Horn & Noll, 1997; Horn & Masunaga, 2000) further argues that Carroll's (1993) research reveals no fewer than eight *different* general factors, with the general factor from one battery or dataset not necessarily being the same as the general factor in other batteries or datasets. More specifically, Horn and Noll (1997) argue: "The problem for theory of general intelligences is that the factors are not the same from one study to another. . . . The different general factors do not meet the requirements for the weakest form of invariance (Horn & McArdle, 1992) or satisfy the conditions of the Spearman model. The general factors represent different mixture measures, not one general intelligence" (p. 68). That is, the general factors fail to meet the *same factor requirement* (Horn, 1998, p. 77).

Second, in what is probably the more convincing portion of Horn's argument, research reveals that "the relationships that putative indicators of general intelligence have with variables of development, neurological functioning, education, achievement, and genetic structure are varied" (Horn & Masunaga, 2000, p. 139). That is, the broad CHC abilities demonstrate differential relations with (1) different outcome criteria (e.g., in the area of academic achievement, see Evans, Floyd, McGrew, & Leforgee, 2002; Floyd, Evans, & McGrew, 2003; McGrew, 1993; McGrew & Hessler, 1995, McGrew & Knopik, 1993); (2) developmental growth curves; (3) neurological functions; and (4) degree of heritability. "The many relationships defining the construct validities of the different broad factors do not indicate a single unitary principle" (Horn & Masunaga, 2000, p. 139). See Horn and Noll (1997) and Horn and Blankson (Chapter 3, this volume) for additional information.

Carroll on *g*

As presented earlier in this chapter, Carroll (2003), in his final publication, tested the *g* versus no-*g* versus "*g* is Gf" models in the WJ-R norm data. He concluded that "researchers who are concerned with this structure in one way or another...can be assured that a general factor *g* exists, along with a series of second-order factors that measure

broad special abilities" (p. 19). He further stated that "doubt is cast on the view that emphasizes the importance of a Gf factor. . . . these data tend to discredit the limited structural analysis view and the second-stratum multiplicity view" (p. 17).

The primary basis for Carroll's belief in *g* stems not necessarily from the positive correlations among dissimilar tasks, but rather "from the three-stratum model that, for a well-designed dataset, yields factors at different strata, including a general factor" (Carroll, 1998, pp. 12–13). Carroll (1998) believed that for each factor in his three-stratum theory, there is a specific "state or substate" (e.g., "structured patterns of potentialities latent in neurons"; Carroll, 1998, p. 10) existing within an individual that accounts for the performance on tasks requiring a specific latent ability—"we can infer that *something* is there" (Carroll, 1998, p. 11; original emphasis). By extension, the emergence of a *g* factor in his EFA-SL work must reflect some form of specific state or substate within an individual.

Carroll (2003) further argued that the different *g* factors he reported (Carroll, 1993) do represent the same construct, given the underlying assumptions and procedures of the EFA-SL approach. In response to Horn's arguments, Carroll stated that Horn

> conveniently forgets a fundamental principle on which factor analysis is based (a principle of which he is undoubtedly aware)—that the nature of a single factor discovered to account for a table of intercorrelations does not necessarily relate to special characteristics of the variables involved in the correlation matrix; it relates only to characteristics or underlying measurements (latent variables) that are common to those variables. I cannot regard Horn's comment as a sound basis for denying the existence of a factor *g*, yet he succeeded in persuading himself and many others to do exactly this for an extended period of years. (p. 19)

Finally, in a personal communication received just prior to his passing away, Carroll (personal communication, June 30, 2003) provided the following comments regarding the "proof" of *g*:

> It is important to recognize that in my paper published in the Nyborg book occurs the first modern, real, scientific proof of *g*—in contrast to the many unacceptable "proofs" claimed by Spearman, Burt, Pearson, and others. It used the features of a complete proof advanced by LISREL technologies. Jöreskog has discussed these features in his many writings . . . of particular interest are the proofs of the status of *g*, Gc, and Gf, as provided in the Nyborg chapter . . . in the sense *g*, Gc and Gf could be independently established, plus several other factors, (e.g. Gv, Ga). It was truly marvelous that enough data from these factors had accumulated to make their independence specifiable.
>
> The "general factor" appears to pertain only to very general items of general knowledge—e.g., items of knowledge that are common to most people, present only as specified by parameters of "item difficulty." *g* thus appears not to pertain to the many items of knowledge incorporated in Gf or Gc. These items of knowledge are in some way special—classified under Gf or Gc (or some combination of these). It appears that a human being becomes a "member of society" only by acquiring aspects of special knowledge (either fluid or crystallized, or some combination of them).

Behind *g*: Working Memory?

Regardless of whether *g* can be proven to represent a specific essence of the human mind, those working in the field of applied intelligence testing need to be familiar with recent research suggesting that certain cognitive processes may lie *behind* the general factor. The integration of a century of psychometric research with contemporary information-processing theories has resulted in important strides in understanding human intelligence (Kyllonen, 1996). Although slightly different information-processing models have been hypothesized and researched, in general the four-source consensus model (Kyllonen, 1996) will suffice for this chapter. According to Kyllonen (1996), the four primary components or sources of this model are *procedural knowledge*, *declarative knowledge*, *processing speed* (Gs), and *working memory* (MW).[21]

One of the most intriguing findings from the marriage of psychometric and information-processing models, first reported by Kyllonen and Christal (1990), is that "individual differences in working memory capacity may be what are responsible for individual differences in general ability" (Kyllonen, 1996, p. 61). This hypothesis was proposed by Kyllonen (Kyllonen, 1996; Kyllonen & Christal, 1990), based on very high latent factor correlations (.80 to the mid-.90s) between measures of MW and Gf in a variety of adult samples. Attempts to understand the relation between MW and higher-order cognition "have occupied researchers for the past 20 years" (Kane, Bleckley, Conway, & Engle, 2001, p. 169). Since 1990, the concept of MW has played a central role in research attempting to explain individual differences in higher-level cognitive abilities, such as language comprehension (Gc; Engle, Cantor, & Carullo, 1992; Just & Carpenter, 1992), reading and mathematics (Grw and Gq; Hitch, Towse, & Hutton, 2001; Leather & Henry, 1994), reasoning or general intelligence (Gf and *g*; Ackerman, Beier, & Boyle, 2002; Conway, Cowan, Bunting, Themault, & Minkoff, 2002; Engle, Tuholski, Laughlin, & Conway, 1999; Fry & Hale, 1996, 2000; Kyllonen & Christal, 1990; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002), and long-term memory performance (Park et al., 1996; Süß et al., 2002).

The theoretical explanations for the consistently strong MW→Gf or *g* criterion relations differ primarily in terms of the different cognitive resources proposed to underlie MW performance (Lohman, 2000). More specifically, *multiple-resource* and *resource-sharing* models have been proposed (Bayliss, Jarrold, Gunn, & Baddeley, 2003). Some examples of resources hypothesized to influence MW performance are storage capacity, processing efficiency, the central executive, domain-specific processes, and controlled attention (Bayliss et al., 2003; Engle et al., 1999; Kane et al., 2001). Researchers have hypothesized that the reason why MW is strongly associated with complex cognition constructs (e.g., Gf) is that considerable information must be actively maintained in MW, especially when some active transformation of information is required. Even if the transformation "process" is effective, it must be performed within the limits of the working memory system. Therefore, although many different processes may be executed in the solution of a task, individual differences in the processes may primarily reflect individual differences, not working memory resources (Lohman, 2000, p. 325). A detailed treatment of the different theoretical explanations for working memory is beyond the scope of the current chapter and is not necessary in the current context. Figure 8.2 presents schematic summaries of four of the primary SEM investigations (published during the past decade) that shed additional insights on the causal relations between MW and *g* or Gf.[22]

In the causal models portrayed in Figure 8.2, MW demonstrates a significant effect on all dependent variables (primarily Gf or *g*).[23] With the exception of the Süß and colleagues (2002) models (Figures 8.2d and 8.2e), the strength of the MW → Gf/*g* (.38 to .60) relations are lower than those reported by Kyllonen and Christal (1990). The weakest MW → Gf relationship (.38) was in the only sample of children and adolescents (Figure 8.2a). This finding may suggest a weaker relationship between the construct of MW and complex cognitive reasoning during childhood. In contrast, when the two different MW components (MW1 and MW2) are considered together in the two alternative Süß and colleagues models, MW collectively exerts a strong influence on *g* (MW1 = .65; MW2 = .40; Figure 8.2d) and Gf (MW1 = .70; MW2 = .24; Figure 8.2e).

It is important to note that in most studies that have explored the relation between MW and psychometric constructs, Gs is typically included as a direct precursor to MW (see Figures 8.2a and 8.2c). Collectively, the MW → criterion studies suggest that MW may be a significant causal factor working *behind* the scenes when complex cognitive performance is required (e.g., Gf or *g*). Missing from this literature are studies that include a broader and more complete array of CHC indicators and factors in larger and more carefully selected samples. This limitation is addressed below.

WJ III CHC MW → *g* Studies

For the purposes of this chapter, select tests from the CHC-designed WJ III COG battery were used to investigate the relations between measures of information-processing efficiency (viz., Gs, MS, and MW) and complex cognitive ability (operationalized in the form of *g*). In the causal model, *g* was operationally defined as a second-order latent factor composed of five well-identified latent CHC factors (Gf, Gc, Glr, Ga, and Gv; McGrew & Woodcock, 2001).[24] Consistent with the extant literature, Gs was specified to be a direct precursor to MW, although all models also tested for significant direct paths from Gs to *g*. In addition, given that MW subsumes the rote storage role of MS, a sepa-

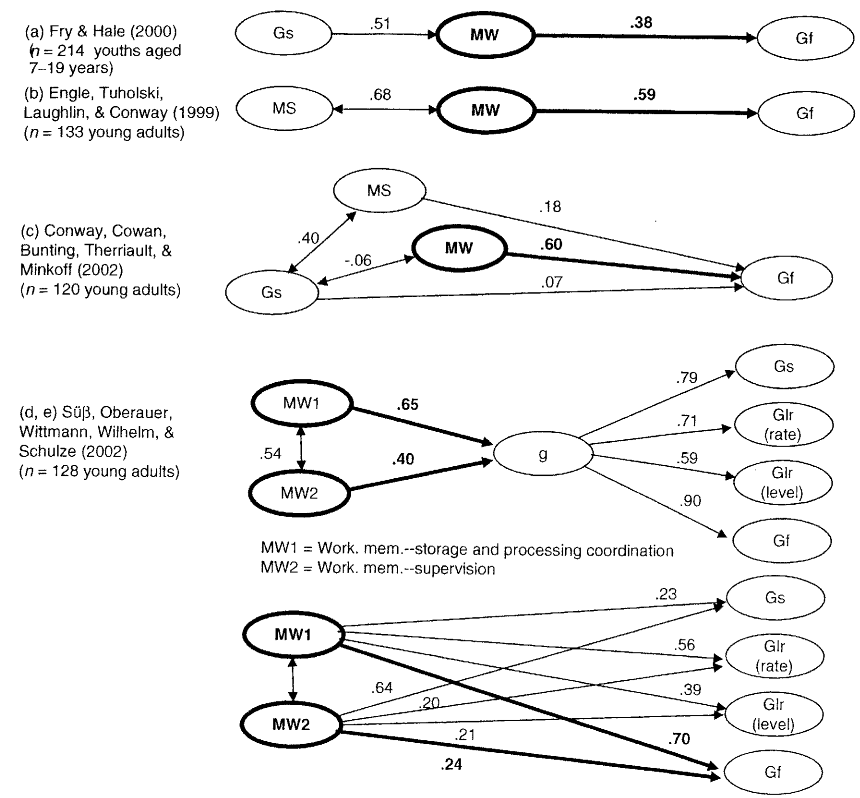

FIGURE 8.2. Working memory →complex cognitive abilities (viz., *g* and Gf) causal models reported from 1993–2003. Ovals represent latent factors. Single-headed arrows represent causal paths (effects). Double-headed arrows represent latent factor correlations. Manifest test indicators and residuals have been omitted for readability purposes. Factors have been renamed from original sources as per CHC theory.

rate MS factor with a direct effect on MW was specified. The inclusion of both MS and MW latent factors is consistent with the research models of Engle and colleagues (1999). The final model is represented in Figure 8.3.

For each of five age-differentiated nationally representative samples (each of which ranged in size from approximately 1,000 to 2,200 subjects; see McGrew & Woodcock, 2001), the same initial model was specified. In addition to the direct MW → *g* path, a direct Gs → *g* path was also tested in each sample (see Figure 8.3).[25] The results summarized in Figure 8.3 and Table 8.4 are important to note, as they allow for the investigation of the MW - *g* relationship in large, nationally representative samples. In addition, the latent factor constructs defined in these analyses are represented by the same indicators across all samples—a condition rarely achieved across independent research studies (e.g., see Figure 8.2). This later condition provides for configural invariance of the models across samples. The parameters presented in Figure 8.3 are for the 14- to 19-year-old sample. Table 8.4 presents the key parameters and model fit statistics for all samples.

The results presented in Figure 8.3 and Ta-

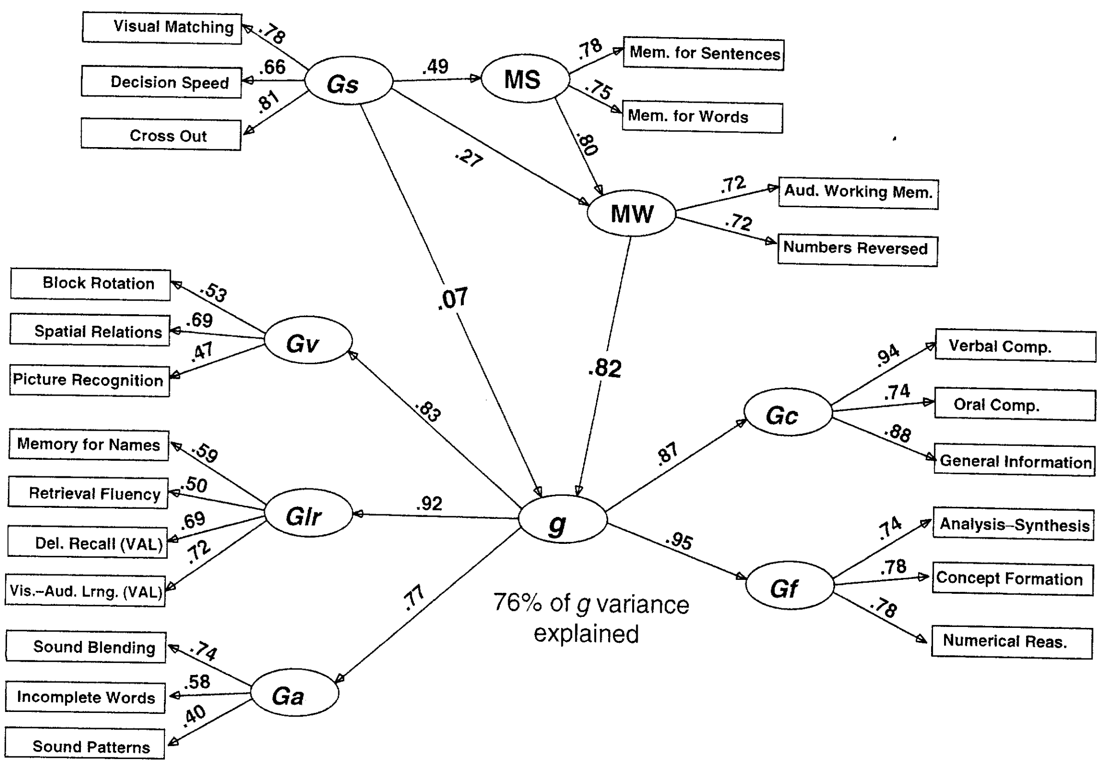

FIGURE 8.3. WJ III CHC information processing MW →*g* causal model (ages 14–19). Ovals represent latent factors. Rectangles represent manifest measures (tests). Single-headed arrows to tests from ovals designate factor loadings. Single-headed arrows between ovals represent causal paths (effects). Test and factor residuals have been omitted for readability purposes.

TABLE 8.4. Select Model Parameters and Fit Statistics for WJ III CHC MW →*g* Models (see Figure 8.3)

		Structural (causal) MW, MS, Gs, *g* paths						Select model fit statistics					
Age group (in years)	% *g* variance explained	MW to *g* path	Gs to *g* path	Gs to *g* total direct + indirect effects	Gs to MS path	MS to MW path	Gs to MW path	GFI[a]	AGFI[b]	CFI[c]	RMSEA[d]	RMSEA[e] (low)	RMSEA[e] (high)
6–8	86%	.93	—	.79	.44	.63	.46	.88	.84	.93	.078	.074	.081
9–13	80%	.90	—	.60	.40	.70	.39	.94	.92	.94	.054	.052	.056
14–19	76%	.82	.07	.61	.49	.80	.27	.93	.91	.94	.058	.055	.061
20–39	80%	.83	.09	.67	.50	.80	.30	.90	.87	.93	.068	.065	.071
40–90+	84%	.73	.22	.81	.61	.63	.43	.88	.84	.93	.078	.074	.081

[a]GFI, goodness-of fit index;
[b]AGFI, adjusted goodness-of fit index;
[c]CFI, normed comparative fit index;
[d]RMSEA, root-mean-square error of approximation;
[e]RMSEA low/high, 95% confidence band for lower and upper limits of RMSEA.

ble 8.4 are consistent with the previously summarized MW → *g* research literature. Across all five samples, the MW → *g* direct-effect path ranged from .73 to .93. Clearly, working memory (MW) potentially exerts a large causal effect on complex cognitive performance (i.e., *g*) when defined by the combined performance on five latent CHC factors (i.e., Gf, Gc, Glr, Ga, Gv). The trend for the MW → *g* path to decrease with increasing age (.93, .90, .82, .83, .73) may be of significant substantive interest to developmental psychologists and intelligence researchers studying the effect of aging within the CHC framework (e.g., see Horn & Masunaga, 2000; Park et al., 1996; Salthouse, 1996). Also of interest is the finding, consistent with prior research (Fry & Hale, 1996, 2000), that Gs did not demonstrate a direct effect on *g* in the childhood samples. However, starting in late adolescence (ages 14–19), Gs begins to demonstrate small yet significant direct effects on *g* (.07 and .09 from ages 14 to 39), and a much more substantial effect at middle age and beyond (.22). These developmental trends suggest the hypothesis that during an individual's formative years (ages 6–13), MW exerts a singular and large (.90 to .93) direct effect on complex cognitive task performance (i.e., *g*). In adolescence, MW appears to decrease slightly in direct influence on *g*, while Gs concurrently increases in importance, particularly during the latter half of most individuals' lives (40 years and above).

It is important to note that in all models, Gs exerts indirect effects on *g* via two routes (i.e., Gs → *MS* → *MW* → *g*; Gs → *MW* → *g*). The total effects (direct + indirect) of Gs on *g* have been calculated via standard path-model-tracing rules, and are summarized in Table 8.4. The range of total Gs → *g* effects is large (.60 to .81). Clearly, these analyses suggest that Gs and MW both exert large and significant influence on complex cognitive performance (i.e., *g*). Collectively, the total effects of Gs + MW (information-processing efficiency)[26] account for 76% to 86% of the CHC-defined *g* factor.

Behind *g*: Summary

The WJ III CHC MW → *g* analyses and research studies presented here continue to suggest an intriguing relation between measures of cognitive efficiency (Gs and MW) and complex cognitive performance (viz., Gf and *g*). As articulated by Kyllonen (1996),

> the remarkable finding is the consistency with which the working memory capacity factor has proven to be the central factor in cognition abilities . . . working memory capacity is more highly related to performance on other cognitive tests, and is more highly related to learning, both short-term and long-term, than is any other cognitive factor. (pp. 72–73)

Leaping from these findings to the conclusion that MW is the basis of Spearman's *g* (Süß et al., 2002) or Gf (Kyllonen & Christal, 1990) is not the intent of this section of this chapter. Alternative claims for the basis of *g* (e.g., processing/reaction time) exist (see Nyborg, 2003). The important conclusion here is that appropriately designed CHC MW → *g* outcome studies can make important contributions to research focused on increasing our understanding of the nature and importance of working memory, as well as the specific cognitive resources that contribute to a variety of cognitive and academic performances. According to Süß and colleagues (2002),

> The strong relationship between working memory and intelligence paves the way for a better understanding of psychometric ability concepts through theories of cognition. Establishing this general association, however, is only the first step. Working memory itself is not a precisely defined construct. It is widely accepted that working-memory capacity is an important limited resource for complex cognition; however, which functions of working memory affect which part of the cognitive process in a given reasoning task is not well understood. . . . Now that the relationship between working memory and intelligence has been established on a molar level, further research with more fine-grained analyses need to be done. (pp. 285–286)

Beyond *g*: CHC Lower-Stratum Abilities Are Important

"The *g* factor (and highly *g*-loaded test scores, such as the IQ) shows a more far-reaching and universal practical validity than any other coherent psychological construct yet discovered" (Jensen, 1998, p. 270). The strength of *g*'s prediction, together with past attempts to move "beyond *g*" (i.e., the addition of specific abilities to *g* in the prediction and explanation of educational and occupational outcomes), historically have not met with consistent success. In his American Psychological Association presidential address, McNemar (1964) concluded that "the worth of the multi-test batteries as differential predictors of achievement in school has not been demonstrated" (p. 875). Cronbach and Snow's (1977) review of the aptitude–treatment interaction research similarly demonstrated that beyond general level of intelligence (*g*), few, if any, meaningful specific ability–treatment interactions existed. Jensen (1984) also reinforced the preeminent status of *g* when he stated that "*g* accounts for all of the significantly predicted variance; other testable ability factors, independently of *g*, add practically nothing to the predictive validity" (p. 101).

In applied assessment settings, attempts to establish the importance of specific abilities above and beyond the full scale IQ (research largely based on the Wechsler batteries) score have typically meet with failure. As a result, assessment practitioners have been admonished to "just say no" to the practice of interpreting subtest scores in individual intelligence batteries (McDermott, Fantuzzo, & Glutting, 1990; McDermott & Glutting, 1997). The inability to move beyond *g* has provided little optimism for venturing beyond an individual's full scale IQ score in the applied practice of intelligence test interpretation. However, Daniel (2000) believes that these critics have probably "overstated" their case, given some of the techniques they have used in their research.[27]

Despite the "hail to the *g*" mantra, several giants in the field of intelligence have continued to question the "conventional wisdom" of complete deference to *g*. Carroll (1993) concluded that "there is no reason to cease efforts to search for special abilities that may be relevant for predicting learning" (p. 676). In a subsequent publication, Carroll (1998) stated: "It is my impression that there is much evidence, in various places, that special abilities (i.e., abilities measured by second- or first-stratum factors) contribute significantly to predictions" (p. 21). Snow (1998) struck a similar chord when he stated that

> certainly it is often the case that many ability–learning correlations can be accounted for by an underlying general ability factor. Yet, there are clearly situations, such as spatial-mechanical, auditory, or language learning conditions, in which special abilities play a role aside from *G*. (p. 99)

In the school psychology literature, various authors (Flanagan, 2000; McGrew, Flanagan, Keith, & Vanderwood, 1997; Keith, 1999) have suggested that advances in theories of intelligence (viz., CHC theory), the development of CHC-theory-driven intelligence batteries (viz., WJ-R, WJ III), and the use of more contemporary research methods (e.g., SEM) argue for continued efforts to investigate the effects of *g* and specific abilities on general and specific achievements. A brief summary of CHC-based *g* + specific abilities → achievement research follows.

CHC *g* + Specific Abilities → Achievement SEM Studies

Using a Gf-Gc framework, Gustafsson and Balke (1993) reported that some specific cognitive abilities may be important in explaining school performance beyond the influence of *g* when (1) a Gf-Gc intelligence framework is used; (2) cognitive predictor and academic criterion measures are both operationalized in multidimensional hierarchical frameworks; and (3) cognitive abilities → achievement relations are investigated with research methods (viz., SEM) particularly suited to *understanding and explaining* (vs. simply *predicting*). The key advantage of the SEM method is that it allows for the simultaneous inclusion of casual paths (effects) from a latent *g* factor, plus specific paths for latent factors subsumed by the *g* factor, to a common dependent-variable factor (e.g., reading). This is not possible when multiple-regression methods are used.

Drawing on the research approach outlined by Gustafsson and Balke (1993), several CHC-designed studies completed during the past decade have identified significant CHC narrow or broad effects on academic achievement, above and beyond the effect of *g*. Using the Cattell–Horn Gf-Gc-based WJ-R norm data, we (McGrew et al., 1997;

Vanderwood, McGrew, Flanagan, & Keith, 2002) found, depending on the age level (five grade-differentiated samples from grades 1–12), that the CHC abilities of Ga, Gc, and Gs had significant cross-validated effects on reading achievement, above and beyond the large effect of *g*. In the grades 1–2 cross-validation sample (n = 232; McGrew et al., 1997), there was a strong direct effect of *g* on reading, which was accompanied by significant specific effects for Ga (.49) on word attack skills and Gc (.47) on reading comprehension. In math, specific effects beyond the high direct *g* effect were reported at moderate levels (generally .20 to .30 range) for Gs and Gf, while Gc demonstrated high specific effects (generally .31 to .50 range). Using the same WJ-R norm data, Keith (1999) employed the same *g* + specific abilities → achievement SEM methods in an investigation of general (*g*) and specific effects on reading and math as a function of ethnic group status. Keith's findings largely replicated the McGrew and colleagues (1997) results and suggested that CHC *g* + specific abilities → achievement relations are largely invariant across ethnic group status.

In a sample of 166 elementary-school-age students, Flanagan (2000) applied the same methodology used in the McGrew and colleagues (1997), Keith (1999), and Vanderwood and colleagues (2002) studies to a WISC-R + WJ-R "cross-battery" dataset. A strong (.71) direct effect for *g* on reading was found, together with significant specific effects for Ga (.28) on word attack and Gs (.15) and Gc (.42) on reading comprehension. More recently, I (McGrew, 2002) reported the results of similar modeling studies with the CHC-based WJ III. In three age-differentiated samples (ages 6–8, 9–13, 14–19), in addition to the ubiquitous large effect for *g* on reading decoding (.81 to .85), significant specific effects were reported for Gs (.10 to .35) and Ga (.42 to .47).

Beyond *g*: Summary

Collectively, the CHC-based *g* + specific abilities → achievement SEM studies reported during the last decade suggest that even when *g* (if it does exist) is included in causal modeling studies, certain specific lower-stratum CHC abilities display significant causal effects on reading and math achievement. Critics could argue that the trivial increases in model fit and the amount of additional achievement variance explained (vis-à-vis the introduction of specific lower-order CHC paths) is not statistically significant (which is the case), and thus that Occam's razor would argue for the simpler models that only include *g*.[28] Alternatively, knee-jerk acceptance of Occam's razor can inhibit scientifically meaningful discoveries. As best stated by Stankov, Boyle, and Cattell (1995) in the context of research on human intelligence, "while we acknowledge the principle of parsimony and endorse it whenever applicable, the evidence points to relative complexity rather than simplicity. Insistence on parsimony at all costs can lead to bad science" (1995, p. 16).

In sum, even when a Carroll *g* model of the structure of human cognitive abilities is adopted, research indicates that a number of lower-stratum CHC abilities make important contributions to understanding academic achievement, above and beyond *g*.[29] Reschly (1997) reached the same conclusion when he stated, in response to the McGrew and colleagues (1997) paper, that "the arguments were fairly convincing regarding the need to reconsider the specific versus general abilities conclusions. Clearly, some specific abilities appear to have potential for improving individual diagnoses. Note, however, that it is potential that has been demonstrated" (p. 238).

CONCLUSIONS AND CAVEATS

"These are exciting times for those involved in research, development, and the use of intelligence test batteries" (McGrew, 1997, p. 172). This 1997 statement still rings true today. Central to this excitement have been the recognition and adoption, within both the theoretical and applied fields of intelligence research and intelligence testing, of the CHC theory of human cognitive abilities (or some slight variation) as the definitive psychometric theory upon which to construct a working taxonomy of cognitive differential psychology. I echo Horn's (1998) and Jensen's (2004) comparisons to the first presentation of Mendelyev's periodic table of elements in chemistry and to Hans von Bülow's "there it is!" declaration upon reading the score of Wagner's *Die Meistersinger*: The order brought to the study, measurement, and assessment of human cognitive abilities by Carroll's (1993) synthesis—a synthesis built on the shoulders of a crowd of psychometric giants (Horn and Jensen included)—has finally provided both intelligence scholars and practitioners with the first empirically based consensus Rosetta stone from which to organize research and practice. This is truly a marvelous development.

Human intelligence is clearly multidimensional. The past decade has witnessed the accumulation of evidence that supports the broad strokes of the hierarchical multiability CHC theory of human cognitive abilities. This new evidence, often derived from studies that gathered data with a wide breadth of ability indicators in large, nationally representative samples, validates the inclusion of the broad (stratum II) abilities of Gf, Gc, Gq, Grw, Glr, Gsm, Gv, Ga, Gs, and Gt in the CHC taxonomy. In addition, past and recent research suggests (see McGrew & Evans, 2004, for a summary) the need to attend to, and possibly incorporate, the additional broad domains of general knowledge (Gkn), tactile abilities (Gh), kinesthetic abilities (Gk), olfactory abilities (Go), and three separate broad speed abilities (Gs, general cognitive speed; Gt, decision/reaction time or speed; and Gps, psychomotor speed) in future research, measurement, and assessment activities. It is also important to note that CHC theory is not based solely on factor-analytic evidence. Developmental, outcome criterion prediction, heritability, and neurocognitive studies add to the network of validity evidence in support of contemporary CHC theory (see Horn & Noll, 1997).

Consistent with Carroll's (1998) self-critique and recommendations for future research, it is important to recognize that the CHC framework is "an open-ended empirical theory to which future tests of as yet unmeasured or unknown abilities could possibly result in additional factors at one or more levels in Carroll's hierarchy" (Jensen, 2004, p. 5). The importance of avoiding a premature "hardening" of the CHC categories has been demonstrated this past decade vis-à-vis the structural research on the domain of cognitive mental speed, where research now suggests a domain characterized by a complex hierarchical structure with a possible *g* speed factor at the same stratum level as psychometric *g* (see McGrew & Evans, 2004). In this case, the CHC taxonomy has been used as the open-ended framework described by Jensen (2004) and as Carroll's (1994) intended "guide and reference for future researchers" (p. 22).

The revisions, additions, and extensions to the CHC taxonomy suggested in this chapter are based on a reasoned review and evaluation of research (again, primarily factor-analytic) spanning the last decade. It is hoped that the proposed CHC theory modifications proposed here enhance the "search for the Holy Grail" of human cognitive ability taxonomies, at least by providing a minor positive movement toward convergence on a more plausible model. However, the proposed CHC taxonomic enhancements summarized here and elsewhere (McGrew & Evans, 2004) require additional research and replication. Reanalysis of Carroll's 460+ datasets with contemporary procedures (viz., CFA), combined with both CFA and Carroll EFA-based exploratory procedures of post-Carroll (1993) datasets, will help elucidate the validity of current and future proposed revisions of the CHC taxonomy.[30]

Finally, although additional cautions and limitations could be enumerated,[31] the seductive powers of a neat and hierarchically organized structural diagram of cognitive abilities must be resisted. Any theory that is derived primarily from a "rectilinear system of factors is . . . not of a form that well describes natural phenomena" (Horn & Noll, 1997, p. 84). By extension, assessment professionals must humbly recognize the inherent artificial nature of assessment tools built upon linear mathematical models. As stated by MacCallum (2003),

> it is abundantly clear that psychological researchers make extensive use of mathematical models across almost all domains of research. . . . It is safe to say that these models all have one thing in common: *They are all wrong.* Simply put, our models are implausible if taken as exact or literal representations of real world phenomena. They cannot capture the complexities of the real world which they purport to represent. At best, they can provide an approximation of the real world that has some substantive meaning and some utility. (pp. 114–115, original emphasis)

IMPLICATIONS AND FUTURE DIRECTIONS

One never notices what has been done; one can only see what remains to be done. . . .

—MARIE CURIE

Space does not allow a thorough discussion of all potential implications of contemporary CHC theory. As a result, only three major points are offered for consideration.

First, the structural research of the past decade demonstrates the dynamic and unfolding nature of the CHC taxonomy. Additional research is needed to better elucidate the structure of abilities in the broad domains of Gkn, Gk, Gh, and Go. In addition, Carroll's primary focus on identifying an overall structural hierarchy necessitated a deliberate ignoring of datasets with small numbers of variables within a single broad domain (Carroll, 1998). I believe that more focused "mining" within each broad (stratum II) domain is rich with possible new discoveries, and will be forthcoming soon. Studies with a molar focus on variables within a single broad domain can provide valuable insights into the structure and relations of the narrow abilities within that domain. With the foundational CHC structure serving as a working map, researchers can return to previously ignored or recently published datasets, armed with both EFA and CFA tools, to seek a better understanding of the narrow (stratum I) abilities. In turn, test developers and users of tests of intelligence need to continue to develop and embrace tools and procedures grounded in the best contemporary psychometric theory (viz., CHC theory; see recommendations by Flanagan et al., 2000; McGrew, 1997; McGrew & Flanagan, 1998).

Second, CHC theory needs to move beyond the mere description and cataloguing of human abilities to provide multilens explanatory models that will produce more prescriptive hypotheses (e.g., aptitude–treatment interactions). A particularly important area of research will be CHC-grounded investigations of the causal relations between basic information-processing abilities (e.g., processing speed and working memory—"behind *g*") and higher-order cognitive abilities (e.g., Gf, *g*, language, reading, etc.). The recent research in this area by a cadre of prominent researchers (Ackerman, Beier, & Boyle, 2002; Ardila, 2003; Baddeley, 2002; Bayliss et al., 2003; Cocchini, Logie, DellaSala, MacPherson, & Baddeley, 2002; Conway et al., 2002; Daneman & Merikle, 1996; Fry & Hale, 2000; Kyllonen, 1996; Lohman, 2001; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Oberauer, Süß, Wilhelm, & Wittmann, 2003; Paas, Renkl, & Sweller, 2003; Paas, Tuovinen, Tabbers, & VanGerven, 2003) has produced promising models for understanding the dynamic interplay of cognitive abilities during cognitive and academic performance.

In addition, a better understanding of human abilities is likely to require an equal emphasis on investigations of both the *content* and *processes* underlying performance on diverse cognitive tasks. In regard to content, the "faceted" hierarchical Berlin intelligence structure model (Beauducel, Brocke, & Liepmann, 2001; Süß et al., 2002) is a promising lens through which to view CHC theory. Older and lesser-used multivariate statistical procedures, such as multidimensional scaling (MDS), need to be pulled from psychometricians' closets to allow for the simultaneous examination of content (facets), processes, and processing complexity.[32] In addition, the promising "beyond *g*" (*g* + specific abilities) research should continue and be extended to additional domains of human performance. The evidence is convincing that a number of lower-stratum CHC abilities make important contributions to understanding academic and cognitive performance, above and beyond the effect of *g*.

Finally, it is time for the CHC taxonomy to go "back to the future" and revisit the original conceptualization of *aptitude,* as updated most recently by Richard Snow and colleagues (Corno et al., 2002). Contrary to many current erroneous assumptions, *aptitude* is not the same as *ability* or *intelligence.* According to Snow and colleagues, *aptitude* is more aligned with the concepts of *readiness*, *suitability*, *susceptibility*, and *proneness*, all of which suggest a "predisposition to respond in a way that fits, or does not fit, a particular situation or class of situations. The common thread is potentiality-a latent quality that enables the development or production, given specified conditions, of some more advanced performance" (Corno et al., 2002, p. 3).

Aptitudes represent the multivariate repertoire of a learner's degree of readiness (propensities) to learn and to perform well in general and domain-specific learning settings. As such, a person's aptitudes must include, along with cognitive and achievement abilities, *affective and conative characteristics*. Intelligence scholars and applied assessment personnel are urged to investigate the contemporary theoretical and empirical research that has married cognitive constructs (CHC and cognitive information processing) with affective and conative traits in the form of *aptitude trait complexes*. Snow and colleagues' aptitude model (Corno et al., 2002; Snow, Corno, & Jackson, 1996), and Ackerman and colleagues' model of intelligence as *process, personality, interests, and knowledge*, should be required reading for all involved in understanding and measuring human performance (Ackerman, 1996; Ackerman & Beier, 2003; Ackerman, Bowen, Beier, & Kanfer, 2001). The CHC taxonomy is the obvious cognitive cornerstone of a model of human aptitude.[33]

Yes. These are indeed exciting times in the ongoing quest to describe, understand, predict, explain, and measure human intelligence and performance.

ACKNOWLEDGMENTS

This chapter is dedicated to the memory of John "Jack" Carroll, "grandmaster of quantitative cognitive science" (Jensen, 2004, p. 1). I would like to thank Jeffrey Evans for his assistance in the literature review for this chapter.

NOTES

1. These broad abilities are defined in Table 8.3 in this chapter.
2. Different sources (Carroll, 1993; Horn & Noll, 1997; Jensen, 1998) list between seven and nine abilities, and also provide slightly different names for the Thurstone PMAs.
3. The 1977 WJ was, at the time, the only individually administered intelligence test battery to include miniature "learning" tasks. The possibility of revising these tests, or developing new tests, that reflected the dynamic assessment methods rooted in Vygotsky's (1978) *zone of proximal development* (Sternberg & Kaufman, 1998) resulted in the inclusion of Carl Haywood, an recognized expert on the test–teach–test dynamic testing paradigm.
4. This was the first of a number of exhilarating meetings with Horn, Carroll, and primary WJ-R revision team members. These sessions also extended into the revision of the subsequent edition (WJ III). Horn and Carroll were generally in agreement regarding most aspects of the human cognitive ability taxonomy, with one exception—the existence of *g*. Suffice it to say, Horn (*g* does not exist) and Carroll (*g* exists) held strong and opposite views on the existence of *g*, and neither convinced the other during exchanges that often were quite "spirited." Their positions are described later in this chapter.
5. The reader is encouraged to read Woodcock's original 1990 article, to gain an appreciation for the significance of the work and why it has played such a significant role in the infusion of CHC theory into the practice of intelligence test development, assessment, and interpretation.
6. In fairness to these batteries, most were developed and published prior to the Cattell–Horn Gf-Gc model's morphing from a latent to a manifest model in the intelligence-testing literature. Hindsight is always 20-20.
7. The concept of applying a theoretical model not originally associated with a published battery to that battery was not a new idea (see Kaufman & Dopplet, 1976). Woodcock's unique contributions were extending this concept beyond application to the Wechsler scales to all available intelligence batteries; basing this "battery-free" interpretive philosophy on the most validated model of the structure of human cognitive abilities; and, most important, superimposing the Gf-Gc structure on batteries based on empirical evidence.
8. The interested reader should review Table 3.5 on pages 110–111 of Carroll (1993) for an example of a Carroll EFA-SL with three orders of factors. During his later years, Carroll recognized the advantages of CFA and encouraged others to use CFA methods to check his 1993 EFA-based results (Carroll, 1998). I had the fortunate opportunity to visit and work with Carroll in Fairbanks, Alaska, 4 weeks prior to his passing away. It was clear, as illustrated in his combined EFA + CFA WJ-R work (2003), that he had blended the two methodologies. His computer disks were full of unpublished EFA + CFA work that he had graciously completed for other researchers, or that represented his analysis of correlation matrices that had been included in manuscripts he had been asked to

review for a number of journals. His approach had clearly evolved to one of first obtaining results from his EFA-SL approach (as described in Chapter 3 of his 1993 book; see Figure 8.1d) and then using those results as the starting point for CFA refinement and model testing (as described in Carroll, 2003; see Figure 8.1e).

9. The complete process used to classify all tests from all major intelligence batteries at stratum I is first described in McGrew (1997).
10. A so-called "tipping point" is the "moment of critical mass, the threshold, the boiling point" (Gladwell, 2000, p. 12) where a movement that has been building over time, generally in small groups and networks, begins to influence a much wider audience.
11. Carroll recognized the CHC umbrella terminology in his last publication (2003), although he also was a bit puzzled over the details of the origin of "so-called CHC (Cattell–Horn–Carroll) theory of cognitive abilities" (p. 18). According to Carroll (2003), "even though I was to some extent involved in this change (as an occasional consultant to the authors and publisher), I am still not quite sure what caused or motivated it" (p. 18). In a personal conversation I had with Jack Carroll regarding this topic (at his daughter's home in Fairbanks, Alaska, on May 26, 2003), Carroll recognized the practical rational for the CHC umbrella term, but was planning to make it clear in the revision of his 1997 CIA chapter that although the CHC umbrella term might make practical sense, he felt strongly that human cognitive abilities consisted of at least three strata and that, in contrast to Horn's position, that *g* exists. He believed his last chapter publication (2003) provided convincing evidence for the existence of *g*. Carroll wanted to make it clear that the overarching CHC umbrella did not reflect his agreement with Horn on all aspects of the structure of human cognitive abilities. Chapter 4 of the present volume is a reprint of his chapter in the 1997 CIA book, and as such preserves his views.
12. Space constraints do not permit a review and summary of other forms of CHC empirical evidence (i.e., heritability, developmental, neurocognitive, outcome/criterion) published during the past decade.
13. See note 8.
14. Unless otherwise indicated, from this point on in this chapter, the factor names as reported by the original investigators are in parentheses. The factor names/CHC abbreviations preceding the names in parentheses reflect my own reinterpretation of the factors as per CHC theory.
15. In this particular paragraph, the factor codes in parentheses reflect my own interpretation and/or factor labeling.
16. The CHC classifications derived from this April 26, 1997 analysis are presented in McGrew and Flanagan (1998).
17. The factor interpretations presented here are based on my interpretation of the McGhee and Lieberman results. They used similar Gf-Gc terminology to provide slightly different, but very similar, factor interpretations.
18. The Buckhalt et al. (2001) Glr factor was defined primarily by measures of Glr, but also had a number of significant loadings from tests that measure Gv abilities. I have repeatedly seen the same type of factor in EFAs of the WJ-R and WJ III norm data.
19. See McGrew and Evans (2004) for a review of this literature and an explanation of the broad ability names and abbreviations reported here.
20. See Daniel (2000) for a discussion of the various issues involved in calculating practical composite IQ scores from intelligence batteries composed of different measures.
21. Another typical description of information-processing models makes distinctions between (1) memory systems—*short-term* and *long-term* memory; (2) types of knowledge—*declarative* and *procedural*; and (3) types of processing—*controlled* and *automatic* (Lohman, 2000).
22. For readability purposes, the manifest variables and certain other latent factors (age factors) were removed from all figures. In addition, based on a reading of the description of the variables used in each study, I changed the original latent factor names in accordance with CHC theory as described in this chapter. These interpretations do not necessarily reflect the interpretations of the authors of the original published studies.
23. Hambrick and Engle (2002) and Park and colleagues (1996) have reported similar causal models with memory performance as the dependent latent variable. In these studies, the MW direct causal paths were .30 and .44. In the Hambrick and Engle study, MW also had an indirect effect (.31) on memory performance that was mediated through a domain-specific knowledge (Gk) factor.
24. WJ III test indicators for the latent factors were selected based on the principles of (1) providing at least two qualitatively different narrow-ability indicators for each broad CHC factor; (2) using tests that were not factorially complex as determined from prior CFA studies (McGrew & Woodcock, 2001); and (3) using tests that were some of the best WJ III CHC factor indicators (McGrew & Woodcock, 2001).
25. Given that the primary purpose of these analyses was to explore the relations between basic information-processing constructs (Gs and Gsm) and *g*, no effort was made to "tweak" the measurement models in each sample in search of slightly better-fitting models. The same configurially invariant measurement model was used across all five samples.
26. In the WJ III, the combination of Gs and MW (Gsm) is referred to, and is quantified as, Cognitive Efficiency (McGrew & Woodcock, 2001).
27. A nice summary of the issues involved in intelligence test profile analysis can be found in Daniel (2000).
28. For researchers, the essence of Occam's razor is that when two competing theories or models make the same level of prediction, the one that is simpler is better.
29. The *g* + specific abilities → achievement studies could be considered to represent the Carroll position on how cognitive abilities predict/explain academic achievement. The Horn position could similarly be operationally defined in research studies that use either SEM or multiple regression of the lower-order CHC variables on achievement (no *g* included in the models). The results of such Horn CHC → achievement models, completed in either the WJ-R or WJ III norm data, can be found in McGrew (1993), McGrew and Hessler (1995), McGrew and Knopik (1993), Evans and colleagues (2002), and Floyd and colleagues (2003). With the exception of Gv, all broad CHC abilities (Gf, Gc, Ga, Glr, Gsm, Gs) are reported to be significantly associated (at different levels that often vary within each ability domain by age) with reading, math, and writing achievement in the Horn CHC → achievement model.
30. See the Institute of Applied Psychometrics *Carroll Human Cognitive Abilities* (HCA) project for details on efforts to complete such analyses (*http://www.iapsych.com/chchca.htm*).
31. See Carroll (1994 and Chapter 4, this volume) and Horn and Noll (1997) for excellent self-criticisms of the CHC theory by the primary contemporary theory architects.
32. For example, in an unpublished MDS analysis of 50 different cognitive and achievement tests from the WJ III battery, I identified, in addition to the primary broad CHC abilities (e.g., Gv, Gf, Gc, etc.), three other dimensions (possibly reflecting intermediate-stratum abilities?) by which to organize and view the diverse array of CHC measures: (1) visual–spatial/figural vs. auditory linguistic; (2) process dominant vs. product dominant; (3) automatic processes vs. controlled processes.
33. In the area of school learning, we (McGrew, Johnson, Cosio, & Evans, 2004) recently presented a research-synthesis-based comprehensive taxonomy (*essential student academic facilitators*) for organizing and understanding the conative and affective components of academic aptitude. The model includes the broad domains of *motivational orientation* (e.g., intrinsic motivation, academic goal orientation, etc.), *interests and attitudes* (e.g., academic interests, attitudes, values), *self-beliefs* (e.g., academic self-efficacy, self-concept, ability conception, etc.), *social/interpersonal abilities* (e.g., prosocial and problem behaviors, social goal setting, etc.), and *self-regulation* (e.g., planning, activation, monitoring, control and regulation, and reaction/reflection strategies).

REFERENCES

Ackerman, P. L. (1996). A theory of adult intellectual development: Process personality, interests, and knowledge. *Intelligence, 22*, 229–259.

Ackerman, P. L., & Beier, M. E. (2003). Intelligence, personality, and interests in the career choice process. *Journal of Career Assessment, 11*(2), 205–218.

Ackerman, P. L., Beier, M. E., & Boyle, M. O. (2002). Individual differences in working memory within a nomological network of cognitive and perceptual speed abilities. *Journal of Experimental Psychology: General, 131*(4), 567–589.

Ackerman, P. L., Bowen, K. R., Beier, M. E., & Kanfer, R. (2001). Determinants of individual differences and gender differences in knowledge. *Journal of Educational Psychology, 93*(4), 797–825.

Ackerman, P. L., & Cianciolo, A. T. (2000). Cognitive, perceptual-speed, and psychomotor determinants of individual differences during skill acquisition. *Journal of Experimental Psychology: Applied, 6*(4), 259–290.

Ackerman, P. L., & Kanfer, R. (1993). Integrating laboratory and field study for improving selection: Development of a battery for predicting air traffic controller success. *Journal of Applied Psychology, 78*(3), 413–432.

Ardila, A. (2003). Language representation and working memory with bilinguals. *Journal of Communication Disorders, 36*(3), 233–240.

Baddeley, A. D. (2002). Is working memory still working? *European Psychologist, 7*(2), 85–97.

Bailey, K. D. (1994). *Typologies and taxonomies: An introduction to classification techniques*. Thousand Oaks, CA: Sage.

Bayliss, D. M., Jarrold, C., Gunn, D. M., & Baddeley, A. D. (2003). The complexities of complex span: Explaining individual differences in working memory in children and adults. *Journal of Experimental Psychology: General, 132*(1), 71–92.

Beauducel, A., Brocke, B., & Liepmann, D. (2001). Perspectives on fluid and crystallized intelligence: Facets for verbal, numerical, and figural intelligence. *Personality and Individual Differences, 30*(6), 977–994.

Bickley, P. G., Keith, T. Z., & Wolfe, L. M. (1995). The three-stratum theory of cognitive abilities: Test of the structure of intelligence across the life span. *Intelligence, 20*(3), 309–328.

Bracken, B. A., & McCallum, R. S. (1998). *The Universal Nonverbal Intelligence Test.* Itasca, IL: Riverside.

Brand, C. R. (1996). Doing something about *g*. *Intelligence, 22*(3), 311–326.

Brody, N. (2000). History of theories and measurements of intelligence. In R. J. Sternberg (Ed.), *Handbook of intelligence* (pp. 16–33). New York: Cambridge University Press.

Buckhalt, J., McGhee, R., & Ehrler, D. (2001). An investigation of Gf-Gc theory in the older adult population: Joint factor analysis of the Woodcock–Johnson—Revised and the Detroit Test of Learning Aptitude—Adult. *Psychological Reports, 88*, 1161–1170.

Burns, R. B. (1994). Surveying the cognitive terrain. *Educational Researcher, 23*(2), 35–37.

Burt, C. (1909). Experimental tests of general intelligence. *British Journal of Psychology, 3*, 94–177.

Burt, C. (1911). Experimental tests of higher mental processes and their relation to general intelligence. *Journal of Experimental Pedagogy and Training, 1*, 93–112.

Burt, C. (1941). *Factors of the mind.* London: University of London Press.

Burt, C. (1949a). The structure of the mind: A review of the results of factor analysis. *British Journal of Psychology, 19*, 176–199.

Burt, C. (1949b). Subdivided factors. *British Journal of Statistical Psychology, 2*, 41–63.

Butler, K. J. (1987). *A factorial invariance study of intellectual abilities from late childhood to late adulthood.* Unpublished doctoral dissertation, University of Denver.

Carroll, J. B. (1983). Studying individual differences in cognitive abilities: Through and beyond factor analysis. In R. F. Dillon (Ed.), *Individual differences in cognition* (Vol. 1, pp. 1–33). New York: Academic Press.

Carroll, J. B. (1985). *Domains of cognitive ability.* Paper presented at the annual meeting of the American Association for the Advancement of Science, Los Angeles.

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

Carroll, J. B. (1994). An alternative, Thurstonian view of intelligence. *Psychological Inquiry, 5*(3), 195–197.

Carroll, J. B. (1998). Human cognitive abilities: A critique. In J. J. McArdle & R. W. Woodcock (Eds.), *Human cognitive abilities in theory and practice* (pp. 5–24). Mahwah, NJ: Erlbaum.

Carroll, J. B. (2003). The higher-stratum structure of cognitive abilities: Current evidence supports *g* and about ten broad factors. In H. Nyborg (Ed.), *The scientific study of general intelligence: Tribute to Arthur R. Jensen* (pp. 5–22). Amsterdam: Pergamon Press.

Carroll, J. B., Davies, P., & Richman, B. (1971). *The American Heritage word frequency book.* Boston: Houghton Mifflin.

Carroll, J. B., & Horn, J. L. (1981). On the scientific basis of ability testing. *American Psychologist, 36*, 1012–1020.

Carroll, J. B., & Maxwell, S. E. (1979). Individual differences in cognitive abilities. *Annual Review of Psychology, 30*, 603–640.

Cattell, R. B. (1941). Some theoretical issues in adult intelligence testing. *Psychological Bulletin, 38*, 592.

Cattell, R. B. (1943). The measurement of adult intelligence. *Psychological Bulletin, 40*, 153–193.

Cattell, R. B. (1957). *Personality and motivation structure and measurement.* New York: World Book.

Cattell, R. B. (1963). Theory for fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology, 54*, 1–22.

Cattell, R. B. (1971). *Abilities: Their structure, growth and action.* Boston: Houghton-Mifflin.

Cattell, R. B., & Horn, J. L. (1978). A check on the theory of fluid and crystallized intelligence with description of new subtest designs. *Journal of Educational Measurement, 15*, 139–164.

Cocchini, G., Logie, R. H., DellaSala, S., MacPherson, S. E., & Baddeley, A. D. (2002). Concurrent performance of two memory tasks: Evidence for domain-specific working memory systems. *Memory and Cognition, 30*(7), 1086–1095.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30*(2), 163–183.

Corno, L., Cronbach, L., Kupermintz, H., Lohman, D., Mandinach, E., Porteus, A., et al. (2002). *Remaking the concept of aptitude: Extending the legacy of Richard E. Snow.* Mahwah, NJ: Erlbaum.

Corsini, R. J. (1999). *The dictionary of psychology.* Philadelphia: Brunner/Mazel.

Cronbach, L. J., & Snow, R. E. (1977). *Aptitudes and instructional methods.* New York: Irvington.

Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin and Review, 3*(4), 422–433.

Daniel, M. H. (1997). Intelligence testing: Status and trends. *American Psychologist, 52*(10), 1038–1045.

Daniel, M. H. (2000). Interpretation of intelligence test scores. In R. J. Sternberg (Ed.), *Handbook of intelligence* (pp. 477–491). New York: Cambridge University Press.

Danthiir, V., Roberts, R. D., Pallier, G., & Stankov, L. (2001). What the nose knows: Olfaction and cognitive abilities. *Intelligence, 29*, 337–361.

Davidson, J. E., & Downing, C. L. (2000). Contemporary models of intelligence. In R. J. Sternberg (Ed.), *Handbook of intelligence* (pp. 34–52). New York: Cambridge University Press.

Deary, I. (2003). Reaction time and psychometric intelligence: Jensen's contributions. In H. Nyborg (Ed.), *The scientific study of general intelligence: Tribute to Arthur R. Jensen* (pp. 53–76). San Diego, CA: Pergamon.

Dunn, G., & Everitt, B. S. (1982). *An introduction to mathematical taxonomy.* New York: Cambridge University Press.

Ekstrom, R. B., French, J. W., Harman, H. H., & Dermen, D. (1976). *Manual for kit of factor-referenced cognitive tests, 1976.* Princeton, NJ: Educational Testing Service.

Ekstrom, R. B., French, J. W., & Harman, H. H. (1979). Cognitive factors: Their identification and replication. *Multivariate Behavioral Research Monographs, 79*(2), 3–84.

Embretson, S. E., & McCollam, S. S. (2000). Psychometric approaches to understanding and measuring intelligence. In R. J. Sternberg (Ed.), *Handbook of intelligence* (pp. 423–444). New York: Cambridge University Press.

Engle, R. W., Cantor, J., & Carullo, J. J. (1992). Individual differences in working memory and comprehension: Test of four hypotheses. *Journal of Experimental Psychology, 18*(5), 972–992.

Engle, R. W., Tuhoski, S. W., Laughlin, J. E., & Conway, A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology: General, 128*(3), 309–331.

Evans, J. J., Floyd, R. G., McGrew, K. S., & Leforgee, M. H. (2002). The relations between measures of Cattell–Horn–Carroll (CHC) cognitive abilities and reading achievement during childhood and adolescence. *School Psychology Review, 31*(2), 246–262.

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*(3), 295–329.

Flanagan, D. P., Genshaft, J. L., & Harrison, P. L. (Eds.). (1997). *Contemporary intellectual assessment: Theories, tests, and issues.* New York: Guilford Press.

Flanagan, D. P., & McGrew, K. S. (1997). A cross-battery approach to assessing and interpreting cognitive abilities: Narrrowing the gap between practice and science. In D. P. Flanagan, J. L. Genshaft, & P. L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (pp. 314–325). New York: Guilford Press.

Flanagan, D. P., & McGrew, K. S. (1998). Interpreting intelligence tests from contemporary Gf-Gc theory: Joint confirmatory factor analysis of the WJ-R and the KAIT in a non-white sample. *Journal of School Psychology, 36*(2), 151–182.

Flanagan, D. P., McGrew, K. S., & Ortiz, S. (2000). *The Wechsler Intelligence Scales and Gf-Gc Theory: A contemporary approach to interpretation.* Needham Heights, MA: Allyn & Bacon.

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

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

Fleishman, E. A., & Quaintance, M. K. (1984). *Taxonomies of human performance.* Orlando, FL: Academic Press.

Floyd, R. G., Evans, J. J., & McGrew, K. S. (2003). Relations between measures of Cattell–Horn–Carroll (CHC) cognitive abilities and mathematics achievement across the school-age years. *Psychology in the Schools, 40*(2), 155–171.

French, J. W. (1951). *The description of aptitude and achievement tests in terms of rotated factors* (Psychometric Monographs, No. 5). Chicago: University of Chicago Press.

French, J. W., Ekstrom, R. B., & Price, L. R. (1963). *Manual and kit of reference tests for cognitive factors.* Princeton, NJ: Educational Testing Service.

Fry, A. F., & Hale, S. (1996). Processing speed, working memory, and fluid intelligence: Evidence for a developmental cascade. *Psychological Science, 7*(4), 237–241.

Fry, A. F., & Hale, S. (2000). Relationships among processing speed, working memory, and fluid intelligence in children. *Biological Psychology, 54*(1–3), 1–34.

Gladwell, M. (2000). *The tipping point: How little things can make a big difference.* Boston: Back Bay Books.

Guilford, J. P. (1967). *The nature of human intelligence.* New York: McGraw-Hill.

Gustafsson, J.-E. (1984). A unifying model for the structure of intellectual abilities. *Intelligence, 8*, 179–203.

Gustafsson, J.-E. (1988). Hierarchical models of individual differences in cognitive abilities. In R. J. Sternberg (Ed.), *Psychology of human intelligence* (Vol. 4, pp. 35–71). Hillsdale, NJ: Erlbaum.

Gustafsson, J.-E. (1989). Broad and narrow abilities in research on learning and instruction. In R. Kanfer, P. L. Ackerman, & R. Cudeck (Eds.), *Abilities, motivation, and methodology: The Minnesota Symposium on Learning and Individual Differences* (pp. 203–237). Hillsdale, NJ: Erlbaum.

Gustafsson, J.-E. (2001). On the hierarchical structure of ability and personality. In J. M. Collis & S. Messick (Eds.), *Intelligence and personality: Bridging the gap in theory and measurement* (pp. 25–42). Mahwah, NJ: Erlbaum.

Gustafsson, J.-E., & Balke, G. (1993). General and specific abilities as predictors of school achievement. *Multivariate Behavioral Research, 28*(4), 407–434.

Gustafsson, J.-E., & Undheim, J. O. (1996). Individual differences in cognitive functions. In D. C. Berliner & R. C. Calfer (Eds.), *Handbook of educational psychology* (pp. 186–242). New York: Macmillan.

Hakstian, A. R., & Cattell, R. B. (1974). The checking of primary ability structure on a basis of twenty primary abilities. *British Journal of Educational Psychology, 44*, 140–154.

Hakstian, A. R., & Cattell, R. B. (1978). Higher stratum ability structure on a basis of twenty primary abilities. *Journal of Educational Psychology, 70*, 657–659.

Hambrick, D. Z., & Engle, R. W. (2002). Effects of domain knowledge, working memory capacity, and age on cognitive performance: An investigation of the knowledge-is-power hypothesis. *Cognitive Psychology, 44*(4), 339–387.

Hitch, G. J., Towse, J. N., & Hutton, U. (2001). What limits children's working memory span? Theoretical accounts and applications for scholastic development. *Journal of Experimental Psychology: General, 130*(2), 184–198.

Horn, J. (1976). Human abilities: A review of research and theory in the early 1970's. *Annual Review of Psychology, 27*, 437–485.

Horn, J. (1998). A basis for research on age differences in cognitive abilities. In J. J. McArdle & R. W. Woodcock (Eds.), *Human cognitive abilities in theory and practice* (pp. 57–92). Mahwah, NJ: Erlbaum.

Horn, J. L. (1965). *Fluid and crystallized intelligence: A factor analytic study of the structure among primary mental abilities*. Unpublished doctoral dissertation, University of Illinois, Champaign.

Horn, J. L. (1968). Organization of abilities and the development of intelligence. *Psychological Review, 75*, 242–259.

Horn, J. L. (1972). State, trait and change dimensions of intelligence: A critical experiment. *British Journal of Educational Psychology, 42*, 159–185.

Horn, J. L. (1988). Thinking about human abilities. In J. R. Nesselroade (Ed.), *Handbook of multivariate psychology* (pp. 645–685). New York: Academic Press.

Horn, J. L. (1991). Measurement of intellectual capabilities: A review of theory. In K. S. McGrew, J. K. Werder, & R. W. Woodcock, *WJ-R technical manual* (pp. 197–232). Chicago: Riverside.

Horn, J. L. (1994). The theory of fluid and crystallized intelligence. In R. J. Sternberg (Ed.), *The encyclopedia of human intelligence* (pp. 443–451). New York: Macmillan.

Horn, J. L., & Bramble, W. J. (1967). Second-order ability structure revealed in rights and wrongs scores. *Journal of Educational Psychology, 58*, 115–122.

Horn, J. L., & Masunaga, H. (2000). New directions for research into aging and intelligence: The development of expertise. In T. J. Perfect & E. A. Maylor (Eds.), *Models of cognitive aging* (pp. 125–159). Oxford: Oxford University Press.

Horn, J. L., & Cattell, R. B. (1966). Refinement and test of the theory of fluid and crystallized intelligence. *Journal of Educational Psychology, 57*, 253–270.

Horn, J. L., & Cattell, R. B. (1967). Age differences in fluid and crystallized intelligence. *Acta Psychologica, 26*, 107–129.

Horn, J. L., & McArdle, J. J. (1992). A practical and theoretical guide to measurement invariance in aging research. *Experimental Aging Research, 18*(3–4), 117–144.

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. 53–91). New York: Guilford Press.

Horn, J. L., & Stankov, L. (1982). Auditory and visual factors of intelligence. *Intelligence, 6*(2), 165–185.

Hunt, E. (1999). Intelligence and human resources: Past, present, and future. In P. L. Ackerman, P. Kyllonen, & R. Roberts (Eds.), *Learning and individual differences: Process, trait, and content determinants* (pp. 3–30). Washington, DC: American Psychological Association.

Jensen, A. R. (1984). Test validity: *g* versus the specificity doctrine. *Journal of Social and Biological Structures, 7*, 93–118.

Jensen, A. R. (1993). Spearman's hypothesis tested with chronometric information-processing tasks. *Intelligence, 17*(1), 47–77.

Jensen, A. R. (1998). *The* g *factor: The science of mental ability*. Westport, CT: Praeger.

Jensen, A. R. (2004). Obituary—John Bissell Carroll. *Intelligence, 32*(1), 1–5.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review, 99*(1), 122–149.

Kane, M. J., Bleckley, M. K., Conway, A. R. A., & Engle, R. W. (2001). A controlled-attention view of working-memory capacity. *Journal of Experimental Psychology: General, 130*(2), 169–183.

Kaufman, A. S., & Doppler, J. E. (1976). Analysis of WISC-R standardization data in terms of the stratification variables. *Child Development, 47*, 165–171.

Kaufman, A. S., Ishikuma, T., & Kaufman, N. L. (1994). A Horn analysis of the factors measured by the WAIS-R, Kaufman Adolescent and Adult Intelligence Test (KAIT), and two new brief cognitive measures for normal adolescents and adults. *Assessment, 1*, 353–366.

Kaufman, A. S., & Kaufman, N. L. (1993). *Kaufman Adolescent and Adult Intelligence Test manual*. Circle Pines, MN: American Guidance Services.

Kaufman, A. S., & Kaufman, N. L. (1994a). *Manual for Kaufman Functional Academic Skills Test (K-FAST)*. Circle Pines, MN: American Guidance Service.

Kaufman, A. S., & Kaufman, N. L. (1994b). *Manual for Kaufman Short Neuropsychological Assessment Procedure (K-SNAP)*. Circle Pines, MN: American Guidance Service.

Kaufman, A. S., & O'Neal, M. (1988). Factor structure of the Woodcock–Johnson cognitive subtests from preschool to adulthood. *Journal of Psychoeducational Assessment, 6*, 35–48.

Keith, T. Z. (1999). Effects of general and specific abilities on student achievement: Similarities and differences across ethnic groups. *School Psychology Quarterly, 14*(3), 239–262.

Keith, T. Z., Kranzler, J. H., & Flanagan, D. P. (2001). What does the Cognitive Assessment System (CAS) measure?: Joint confirmatory factor analysis of the CAS and the Woodcock–Johnson Tests of Cognitive Ability (3rd edition). *School Psychology Review, 30*(1), 89–119.

Kyllonen, P. C. (1996). Is working memory capacity Spearman's *g*? In I. Dennis & P. Tapsfield (Eds.), *Human abilities: Their nature and measurement* (pp. 49–76). Mahwah, NJ: Erlbaum.

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working-memory capacity?! *Intelligence, 14*, 389–433.

Lamb, K. (1994). Genetics and Spearman's "g" factor. *Mankind Quarterly, 34*(4), 379–391.

Leather, C. V., & Henry, L. A. (1994). Working memory span and phonological awareness tasks as predictors of early reading ability. *Journal of Experimental Child Psychology, 58*, 88–111.

Li, S., Jordanova, M., & Lindenberger, U. (1998). From good senses to good sense: A link between tactile information processing and intelligence. *Intelligence, 26*(2), 99–122.

Lohman, D. F. (1994). Spatially gifted, verbally inconvenienced. In N. Colangelo, S. G. Assouline, & D. L. Ambroson (Eds.), *Talent development: Vol. 2. Proceedings from the 1993 Henry B. and Jocelyn Wallace National Research Symposium on Talent Development* (pp. 251–264). Dayton, OH: Ohio Psychology Press.

Lohman, D. F. (2000). Complex information processing and intelligence. In R. J. Sternberg (Ed.), *Handbook of intelligence* (pp. 285–340). New York: Cambridge University Press.

Lohman, D. F. (2001). Issues in the definition and measurement of abilities. In J. M. Collis & S. Messick (Eds.), *Intelligence and personality: Bridging the gap in theory and measurement* (pp. 79–98). Mahwah, NJ: Erlbaum.

Lubinski, D. (2000). Scientific and social significance of assessing individual differences: "Sinking shafts at a few critical points." *Annual Review of Psychology, 51*, 405–444.

MacCallum, R. C. (2003). Working with imperfect models. *Multivariate Behavioral Research, 38*(1), 113–139.

McDermott, P. A., Fantuzzo, J. W., & Glutting, J. J. (1990). Just say no to subtest analysis: A critique on Wechsler theory and practice. *Journal of Psychoeducational Assessment, 8*, 290–302.

McDermott, P. A., & Glutting, J. J. (1997). Informing stylistic learning behavior, disposition, and achievement through ability subtests—or, more illusions of meaning? *School Psychology Review, 26*, 163–175.

McGhee, R., & Lieberman, L. (1994). Gf-Gc theory of human cognition: Differentiation of short-term auditory and visual memory factors. *Psychology in the Schools, 31*, 297–304.

McGrew, K. S. (1986). A review of the differential predictive validity of the Woodcock–Johnson Scholastic Aptitude clusters. *Journal of Psychoeducational Assessment, 4*, 307–317.

McGrew, K. S. (1987). Exploratory factor analysis of the Woodcock–Johnson Tests of Cognitive Ability. *Journal of Psychoeducational Assessment, 5*, 200–216.

McGrew, K. S. (1993). The relationship between the WJ-R Gf-Gc cognitive clusters and reading achievement across the lifespan. *Journal of Psychoeducational Assessment, Monograph Series: WJ-R Monograph*, 39–53.

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. 151–179). New York: Guilford Press.

McGrew, K. S. (2002). *Advanced interpretation of the Woodcock–Johnson III*. Workshop presented at the annual convention of the National Association of School Psychologists, Chicago.

McGrew, K. S., & Evans, J. (2004). *Carroll Human Cognitive Abilities Project: Research Report No. 2. Internal and external factorial extensions to the Cattell–Horn–Carroll (CHC) theory of cognitive abilities: A review of factor analytic research since Carroll's seminal 1993 treatise*. St. Cloud, MN: Institute for Applied Psychometrics.

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*(2), 189–210.

McGrew, K. S., Gregg, N., Hoy, C., Stennett, R., Davis, M., Knight, D., et al. (2001). *Cattell–Horn–Carroll confirmatory factor analysis of the WJ III, WAIS-III, WMS-III and KAIT in a university sample*. Manuscript in preparation.

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., Johnson, D. R., Cosio, A., & Evans, J. (2004). *Increasing the chance of no child being left behind: Beyond cognitive and achievement abilities*. Minneapolis: University of Minnesota, Institute on Community Integration.

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). *WJ-R technical manual*. Chicago: Riverside.

McGrew, K. S., & Woodcock, R. W. (2001). *Woodcock–Johnson III technical manual*. Itasca, IL: Riverside.
McGue, M., Shinn, M., & Ysseldyke, J. (1979). *Validity of the Woodcock–Johnson Psycho-Educational Battery with learning disabled students* (Research Report No. 15). Minneapolis: University of Minnesota, Institute of Research on Learning Disabilities.
McGue, M., Shinn, M., & Ysseldyke, J. (1982). Use of the cluster scores on the Woodcock–Johnson Psycho-Educational Battery with learning disabled students. *Learning Disability Quarterly, 5*, 274–287.
McNemar, Q. (1964). Lost: Our intelligence? Why? *American Psychologist, 19*, 871–872.
Miyake, A., Friedman, N. P., Rettinger, D. A., Shah, P., & Hegarty, P. (2001). How are visuospatial working memory, executive functioning, and spatial abilities related?: A latent-variable analysis. *Journal of Experimental Psychology: General, 130*(4), 621–640.
Naglieri, J., & Das, J. P. (1997). *Das–Naglieri Cognitive Assessment System (CAS)*. Itasca, IL: Riverside.
Neisser, U., Boodoo, G., Bouchard, T. J. Jr., Boykin, A. W., Brody, N., Ceci, S. J., et al. (1996). Intelligence: Knowns and unknowns. *American Psychologist, 51*(2), 77–101.
Nettelbeck, T. (2003). Inspection time and *g*. In H. Nyborg (Ed.), *The scientific study of general intelligence: Tribute to Arthur R. Jensen* (pp. 77–92). San Diego, CA: Pergamon.
Neuman, G. A., Bolin, A. U., & Briggs, T. E. (2000). Identifying general factors of intelligence: A confirmatory factor analysis of the Ball Aptitude Battery. *Educational and Psychological Measurement, 60*(5), 697–712.
Nyborg, H. (Ed.). (2003). *The scientific study of general intelligence: Tribute to Arthur R. Jensen*. Amsterdam: Pergamon Press.
Oberauer, K., Süß, H.-M., Wilhelm, O., & Wittman, W. W. (2003). The multiple faces of working memory: Storage, processing, supervision, and coordination. *Intelligence, 31*(2), 167–193.
O'Connor, T. A., & Burns, N. R. (2003). Inspection time and general speed of processing. *Personality and Individual Differences, 35*(3), 713–724.
Paas, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist, 38*(1), 1–4.
Paas, F., Tuovinen, J. E., Tabbers, H., & VanGerven, P. W. M. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational Psychologist, 38*(1), 63–71.
Pallier, G., Roberts, R. D., & Stankov, L. (2000). Biological versus psychometric intelligence: Halstead's (1947) distinction revisited. *Archives of Clinical Neuropsychology, 15*(3), 205–226.
Park, D. C., Lautenschlager, G., Smith, A. D., Earles, J. L., Frieske, D., Zwahr, M., & Gaines, C. L. (1996). Mediators of long-term memory performance across the life span. *Psychology and Aging, 11*(4), 621–637.
Phelps, L., McGrew, K., Knopik, S., & Ford, L. (in press). The general (*g*), broad and narrow CHC stratum characteristics of the WJ III and WISC-III tests: A confirmatory cross-battery investigation. *School Psychology Quarterly.*
Prentky, R. A. (1996). Teaching machines. In R. J. Corsini & A. J. Auerbach (Eds.), *Concise encyclopedia of psychology* (2nd ed., Vol. 3, p. 509). New York: Wiley.
Reed, M. T., & McCallum, R. S. (1995). Construct validity of the Universal Nonverbal Intelligence Test (UNIT). *Psychology in the Schools, 32*, 277–290.
Reschly, D. (1997). Utility of individual ability measures and public policy choices for the 21st century. *School Psychology Review, 26*, 234–241.
Roberts, R. D., Nelson-Goff, G., Anjoul, F., Kyllonen, P. C., Pallier, G., & Stankov, L. (2000). The Armed Services Vocational Aptitude Battery (ASVAB): Little more than acculturated learning (Gc)!? *Learning and Individual Differences, 12*(1), 81–103.
Roberts, R. D., Pallier, G., & Nelson-Goff, G. (1999). Sensory processes within the structure of human cognitive abilities. In P. L. Ackerman, P. C. Kyllonen, & R. D. Roberts (Eds.), *Learning and individual differences* (Vol. 15, pp. 339–368). Washington, DC: American Psychological Association.
Roberts, R. D., Pallier, G., & Stankov, L. (1996). The basic information processing (BIP) unit, mental speed and human cognitive abilities: Should the BIP R.I.P.? *Intelligence, 23*, 133–155.
Roberts, R. D., & Stankov, L. (1999). Individual differences in speed of mental processing and human cognitive abilities: Toward a taxonomic model. *Learning and Individual Differences, 11*(1), 1–120.
Roberts, R. D., Stankov, L., Pallier, G., & Dolph, B. (1997). Charting the cognitive sphere: Tactile–kinesthetic performance within the structure of intelligence. *Intelligence, 25*, 111–148.
Roid, G. H. (2003). *Stanford–Binet Intelligence Scales, Fifth Edition*. Itasca, IL: Riverside.
Roid, G. H., Woodcock, R. W., & McGrew, K. S. (1997). *Factor analysis of the Stanford–Binet L and M Forms*. Unpublished manuscript, Riverside Publishing, Itasca, IL.
Rossman, B. B., & Horn, J. L. (1972). Cognitive, motivational and temperamental indicants of creativity and intelligence. *Journal of Educational Measurement, 9*, 265–286.
Rosso, M., & Phelps, L. (1988). Factor analysis of the Woodcock–Johnson with conduct disordered adolescents. *Psychology in the Schools, 25*, 105–110.
Royce, J. R. (1973). The conceptual framework for a multi-factor theory of individuality. In J. R. Royce (Ed.), *Multivariate analysis and psychological theory* (pp. 305–407). New York: Academic Press.
Salthouse, T. A. (1996). The processing-speed theory of adult age differences in cognition. *Psychological Review, 103*(3), 403–428.
Schrank, F. A., Flanagan, D. P., Woodcock, R. W., & Mascolo, J. T. (2002). *Essentials of WJ III cognitive abilities assessment*. New York: Wiley.
Snow, R. E. (1998). Abilities and aptitudes and achievements in learning situations. In J. J. McArdle & R. W. Woodcock (Eds.), *Human cognitive abilities in theory and practice* (pp. 93–112). Mahwah, NJ: Erlbaum.
Snow, R. E., Corno, L., & Jackson, D. (1996). Individual differences in affective and conative functions. In D. C. Berliner & R. C. Calfee (Eds.), *Handbook of educational psychology* (pp. 243–310). New York: Simon & Schuster Macmillan.
Spearman, C. E. (1904). "General Intelligence," objectively determined and measured. *American Journal of Psychiatry, 15*, 201–293.
Spearman, C. E. (1927). *The abilities of man: Their nature and measurement*. London: Macmillan.
Spearman, C. E., & Wynn Jones, L. (1950). *Human ability: A continuation of "The abilities of man."* London: Macmillan.
Stankov, L. (1994). The complexity effect phenomenon is an epiphenomenon of age-related fluid intelligence decline. *Personality and Individual Differences, 16*(2), 265–288.
Stankov, L. (2000). Structural extensions of a hierarchical view on human cognitive abilities. *Learning and Individual Differences, 12*(1), 35–51.
Stankov, L., Boyle, G. J., & Cattell, R. B. (1995). Models and paradigms in personality and intelligence research. In D. H. Saklofske & M. Zeidner (Eds.), *International handbook of personality and intelligence* (pp. 15–44). New York: Plenum Press.
Stankov, L., & Horn, J. L. (1980). Human abilities revealed through auditory tests. *Journal of Educational Psychology, 72*, 21–44.
Stankov, L., Seizova-Cajic, T., & Roberts, R. D. (2001). Tactile and kinesthetic perceptual processes within the taxonomy of human cognition and abilities. *Intelligence, 29*(1), 1–29.
Sternberg, R. J. (1994). *The encyclopedia of human intelligence*. New York: Macmillan.
Sternberg, R. J., & Kaufman, J. C. (1998). Human abilities. *Annual Review of Psychology, 49*, 1134–1139.
Süß, H.-M., Oberauer, K., Wittmann, W. W., Wilhelm, O., & Schulze, R. (2002). Working-memory capacity explains reasoning ability—and a little bit more. *Intelligence, 30*(3), 261–288.
Taub, G. E., & McGrew, K. S. (2004). A confirmatory factor analysis of Cattell–Horn–Carroll theory and cross-age invariance of the Woodcock–Johnson tests of cognitive abilities III. *School Psychology Quarterly, 19*(1), 72–87.

Thurstone, L. L. (1938). The perceptual factor. *Psychometrika, 3*, 1–17.
Thurstone, L. L. (1947). *Multiple factor analysis*. Chicago: University of Chicago Press.
Thurstone, L. L., & Thurstone, T. G. (1941). *Factorial studies of intelligence* (Psychometric Monographs, No. 2). Chicago: University of Chicago Press.
Tirre, W. C., & Field, K. A. (2002). Structural models of abilities measured by the Ball Aptitude Battery. *Educational and Psychological Measurement, 62*(5), 830–856.
Tulsky, D. S., & Price, L. R. (2003). The joint WAIS-III and WMS-III factor structure: Development and cross-validation of a six-factor model of cognitive functioning. *Psychological Assessment, 15*(2), 149–162.
Vanderwood, M. L., McGrew, K. S., Flanagan, D. P., & Keith, T. Z. (2002). The contribution of general and specific cognitive abilities to reading achievement. *Learning and Individual Differences, 13*, 159–188.
Vernon, P. E. (1950). *The structure of human abilities*. New York: Wiley.
Vernon, P. E. (1961). *The structure of human abilities* (2nd ed.). London: Methuen.
Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. (M. Cole, V. John-Stiner, S. Scribner, & E. Souberman, Eds. & Trans.) Cambridge, MA: Harvard University Press.
Woodcock, R. W. (1978). *Development and standardization of the Woodcock–Johnson Psycho-Educational Battery*. Hingham, MA: 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. (1994). Measures of fluid and crystallized intelligence. In R. J. Sternberg (Ed.), *The encyclopedia of human intelligence* (pp. 452–456). New York: Macmillan.
Woodcock, R. W., & Johnson, M. B. (1977). *Woodcock–Johnson Psycho-Educational Battery*. Hingham, MA: Teaching Resources.
Woodcock, R. W., & Johnson, M. B. (1989). *Woodcock–Johnson Psycho-Educational Battery—Revised*. Chicago: Riverside.
Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock–Johnson III*. Itasca, IL: Riverside.

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