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 academic circles, the breakthroughs in objectively gauging the nature and range of mental abilities is a pivotal development in the behavioral sciences. While this accomplishment has profound reaching implications for many areas of society, the full meaning of the test data has lacked a comprehensive theory that accounts for 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 sought order in their world. Today classification is thought of as essential to all scientific work (Dunn & Evans, 1982). The reliable and valid classification of entities, and research regarding these entities and newly proposed entities, requires a "guide" or taxonomy (Riley, 1984; Pressly, 1986). 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. 131). 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 psychodiagnostic assessment batteries” (p. 151).

This 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 (Stemberg & Kaufman, 1998), “the most influential approach, and the one that has generated the most influential research, is based on psychometric theory” (Neisser et al., 1996, p. 93). The CHC theory of intelligence is the test that houses the two most prominent psychometric theoretical models of human cognitive abilities (Daniel, 1997; Snow, 1998; Stemberg & Kaufman, 1998). CHC theory represents the broadest 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 interrelationships of scores on mental ability tests. To develop these models, large numbers of people are given many types of mental problems. Each of these tests 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. Contempory 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.
The Fortuitous Horn—Carrell Woodcock Meeting

In the fall of 1985, I was engaged as a consultant and revision team member for the Woodcock-Johnson—Revised (WI-R; Woodcock & Johnson, 1989). The first order of business was to attend a 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 the test, and also to determine whether "dynamic" testing concepts could be incorporated into the WI-R. At the last minute, the president of the publisher of the WI-R, Developmental Learning Materials, Andy Bingham, made a fortuitous unilateral decision to invite to (to the March 1986 WI-R meeting) an educational psychologist who had worked with on the American Heritage Word Frequency Book (Carroll, Davies, & Richman, 1971). This educational psychologist, whom few members of the WI-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 GI-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 "Gh 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 squared-cornered brown leather briefcase from his side, placed it on the table, and proceeded to remove a thick computer printout (of the old green ink white barred tractor-feed variety associated with mainframe printers). Carroll proceeded to present the results of a just-completed test on the Schmidt—Leiman EPA of the correlation matrices from the 1977 WJ technical manual. A collective "Ah ha!" engulfed the room as Carroll's WI-R 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 Carrell Horn GI-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 assessment developments.

A fortuitous set of events had resulted in the psychotic stars' aligning themselves in perfect position to lead the way for every CHC assessment-related development.


With a Carrell—Horn GI-Gc map in hand, I was directed to organize the available WJ-R factor- and cluster-analytic research studies (Kaufman & O'Neil, 1988; McGrew, 1986, 1987; McFarland & Xyseldyke, 1979; 1982; Rosso & Phelps, 1988; Woodcock, 1978). Pivotal to this search for WJ GI-Gc structure were factor analyses of the WJ-R 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 CPA 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 GI-Gc abilities, as well as suggesting GI-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 each of seven GI-Gc abilities (Carrell Horn GI-Gc broad abilities).

The publication of the WJ-R Tests of Cognitive Abilities (COG) represented the official "crossing over" of GI-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., Carrell—Horn GI-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—Carrell GI-Gc theory in a publication specifically accessible to assessment practitioners. As a direct result of the publication of the WJ-R, "GI-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 listserves.

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

In 1990, Woodcock published an article that, in a sense, provided a "battery-free" approach to GI-Gc theoretical interpretation of all intelligence test batteries. In a seminal article summarizing his analysis of a series of joint CPA studies of the major intelligence batteries (i.e., the Kaufman Assessment Battery for Children—KABC—, 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 Carrell—Horn GI-Gc model. For example, the WJ-R Visual—Auditory Learning test was classified by Woodcock as a strong measure of GI, based on a median factor loading of .697 across 14 different analyses. Another strong measure classification was the SB—IV Vocabulary as a strong measure of Gc, based on a median factor loading of .810 across four analyses.

In the second edition of COG, Woodcock demonstrated how each individual test from each intelligence battery mapped onto the Carrell—Horn GI-Gc taxonomy. The resulting tables demonstrated how each battery adequately measured certain GI-Gc domains, but failed to measure, or measured poorly, other GI-Gc domains. More importantly, Woodcock (1996) suggested that in order to measure a greater breadth of GI-Gc abilities, users of other instruments should use "cross-battery" methods to fill their respective GI-Gc measurement voids. The concept of GI-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 hitched the idea of GI-Gc "battery-free" assessment, in which a comprehensive GI-Gc assessment and interpretable taxonomy were deployed in subsequent intelligence batteries. Practitioners were no longer constrained to the interpretive structure pro-
vated by a specific intelligence battery. Practi-
ctioners were given permission and a ratio-
nale to “think outside their test kits” in order
to conduct more valid assessments. Based on
Woodcock’s (1990) findings, (1, 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 cross-battery assessment approach was wasting the efforts, and McGrew con-
sciously duned the next set of major CHC theory-to-practice bridging events.

Carroll’s 1993 Princpia: 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 “princpia” publications in other fields (e.g., Newton’s three-volume The Mathematical Principles of Natural Philosophy, or Principia as it became known; Whitehead’s and Russell’s Principia Mathematica; see section D in Table 8.1). Briefly, Carroll sum-
marized 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 differences for many years to come.” Burt (1994) was similarly im-
pressed when he stated that Carroll’s book “is simply the finest work of research and scholarship I have ever read and is destined to be the classic 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 of findings is the “definitive foundation for current theory”) (p. 58); he also compared Carroll’s summary to Mendelsohn’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 synthe-
sizes the results of a century of factor analyses of mental tests. It is virtually the grand finale of the era of the psychometric description of the human cognitive abilities. It is unlikely that his monumental feat will ever be at-
tempered again by anyone, or that it could be much improved on. It will long be the key ref-

erence point and a solid foundation for the ex-

planatory 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 tire-
less research by a diverse array of dedicated scholars (e.g., Spearman, Burt, Carroll, Guadino, Horn, Thurstone, Guilford, etc.). Carroll (1993) recognized that his the-
torical model built on the research of oth-

ers and the work of Carroll and Horn. According to Carroll, the Horn-Carr Gf-Gc model “appears to offer the most well-founded and rea-

sonable approach to an acceptable theory of the structure of cognitive abilities.” (p. 62).

The beauty of this book was that for the first time ever, an empirically based taxo-

nomy of human cognitive ability elements, based on the analysis (with a common method) of the vast literature since Spearman, was presented in a single, co-

herent, organized, systematic framework. Lubinski (2000) put a cast on the na-

ture and importance of Carroll’s princpia when he stated that “Carroll’s (1993) three-

stratum theory is, in many respects, not new. Embryonic outlines are seen in earlier psy-

chometric work (Burt, Carroll, Guilman, 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 hu-

man cognitive abilities in which he differentiates abilities as a function of breadth. At the broadest level (stratum III) is a general in-


telligence factor, conceptually similar to Spearman’s and Vernon’s g. Next in breadth are eight broad abilities that represent “basic cognitive operations and long-standing character-

istics of individuals that can govern or influ-

ence a great variety of behaviors in a given domain” (Carroll, 1993, p. 634). Stratum II in-
cludes the abilities of fluid intelligence (Gf), crystallized intelligence (Gc), general memory and learning (Gy), broad visual per-
ception (Gv), broad auditory perception (Ga), broad retrieval ability (Gr), broad cogni-
tive speediness (Gs), and reaction time/decision speed (Gt). Finally, stratum level I in-
cludes numerous narrow abilities that are subsumed by the stratum II abilities, which in turn are subserved 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 EPA with the Schmid-Leiman orthogonalization procedure (EFA-LSI). The typical depiction of Carroll’s model looks much like the CHC theory model (Figure 8.1e). In reality, assum-
ing a three-order (three-stratum) factor solu-
tion, Carroll’s analyses looked more like Fig-

ure 1d, where the following elements are presented: (1) All tests’ loading on the third-

order g factor (arrows from G to T1-T2; omitted from figure); (2) salient loadings for tests on the respective first-order factors (e.g., arrows from PM1A to T1-T3); (3) sal-
ient loadings for tests on their respective second-order factor(s) (e.g., arrows from Gs to T1-T6); (4) positive second-order factors’ loading on their respective second-order factor(s) (e.g., arrows from Gs to PM1A and PM2A); and (5) second-order factors’ loading on the third-order g factor (e.g., arrows from Gs to Gs and to Gl).

In a sense, Carroll provided the field of in-

telligence 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 influen-
tial in creating the awareness among intelli-

gence scholars, applied psychometricians, and assessment professionals, that under-

standing human cognitive abilities required three-stratum vision. As a practical benefit, Carroll’s work provided a common nomen-

clature for professional communication—a nomenclature that should go “far in helping us all better understand what we are measur-

ing, 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 provisory three-stratum ability structural framework should not be minimized. Such a structure, grounded in a large body of con-

derent and discriminant validity research, is the first of at least a dozen conditions re-

quired 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 Carroll-Horn Gf-Gc view, and subsequently, and the publication of the Carroll-Horn Gf-Gc-based WJ-R was reflected in the fact that nine chapters were either devoted to, or in-
cluded significant treatments of, the Carroll-

Horn Gf-Gc and/or Carroll three-stratum theories in Flanagan, Genshaft, and Harris-

son’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 in-

tended for university trainers and assessment practitioners that included chapters describ-
ing both the Carroll-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 techni-

cal manual (McGrew et al., 1991), the CIA book provided a broad-overview introduc-
tion of the “state of the art” of contempo-

rarily psychometric theories of intelligence to the professional keepers of the gate in the intelligence-testing trade (e.g., school psychologists).

Second, Flanagan and I, while digesting
the implication of the need for three-stratum modeling (as articulated by Carroll) and collaboratively investigating with a WJ-R–Kauffman Adaptive Intelligence and Adult Intelligence Test (KAIT) cross-battery assessment (Flanagan & McGrew, 1998; Flanagan & Woodcock, 1990) that realized the prior Gf-Gc test classification. The Flanagan & McGrew, 1998) realized that the prior Gf-Gc test classification was not a comprehensive or stratum II level, and level"--to stratum I or the narrow-ability was needed. Neither the Carroll-Horn nor instead, a "synthesized Carroll and Horn" (p. 152) was developed, based on both Horn’s unpublished EFA-SI, the WJ-R 8.1. Finally, included in the CFA book was the first formal description of the assumptions, foundations, and operationalized set of principles for Gf-Gc cross-battery assessment in Table 8.1. The cross-battery assessment of Woodcock (1990) had given birth to the subsequent spreading of the assessment gos & McGrew, 1997; Flanagan, & Ortt, 2000, McGrew, Flanagan, Ortt, Alfonso, & Mascaro, 2002; Flanagan & McGrew, 1999). Section 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., Cognitive Assessment System [CASS], the Differential Ability Scales [DAS], the K-ABC, the SB-IV, the Wechsler Intelligence Scale for Children–Third Edition [WISC-III]). The normalization of Gf-Gc cross-battery assessment, primarily as the result of Woodcock’s work, was another Daniel & McGrew, 1997) described the cross-battery assessment as a "intrusive" and "creative work cognitive abilities within the framework of a single multifactor model" (p. 1043). Gf-Gc cross-battery assessment did not serve, heritage, publisher, type of carrying: prominent authors (dead or alive), or presence of absence of manipulative or a performance scale. The cumulative impacts of the introduction of Gf-Gc, in particular, the classical and current models of Gf-Gc, the influential WJ-R and Carroll-Horn’s 1993 principles, established a Gf-Gc theory for the first time. The intelligence and artificial intelligence tests 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 Caroll-Horn–Carroll model in Flanagan and col- lator effort to create a single Gf-Gc taxonomy for use in the evaluation and interpretation of intelligence batteries was the integrated Caroll-Horn–Carroll model (McGrew, 1997) (“p. 28). The derivation of the name Caroll-Horn–Carroll (CHC) theory remains a mystery to my knowledge, the first formal published definition of CHC theory was presented in the WJ III technical manual (McGrew & Woodcock, 2003; see section F5 in Table 8.1). Caroll-Horn–Carroll’s theory of cognitive abilities. An amalgamation of two similar theories about the content and structure of human cognitive abilities (Carroll & J. L. Horn, personal communication, July 1999). The first of these two theories is Gf-Gc theory (Carrell, 1993) three-stratum theory. CHC theory is the most comprehensive and empirically supported framework available for understanding the structure of human cognitive abilities. (p. 9)

Despite the forthright Gf-Gc theory had achieved in the field of applied intelligence testing prior to 1999, the term “Gf-Gc” was often met with puzzlement by recipients of psychological reports, sounding esoteric and nonmeaningful, and continued unintentionally to convey the inaccurate belief that the theory was a two-factor model (Gf and Gc). Despite this fact, it had evolved to a model of eight or nine broad abilities. Have dealt with this communication problem in 1989 with 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 that the sequence of correspondences resulting in a verbal agreement that the phrase “Caroll-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 Caroll-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 Carroll and Horn, and Carroll, respectively. Table 8.2 compares and contrasts the major similarities and differences between the Caroll-Horn Gf-Gc and Carroll three-stratum models. As described above, the CHC model (Figure 8.1c) 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 bridge and a more complete and better understanding of the structure of human cognitive abilities.

EMPIRICAL EVALUATION 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 (me- dium number of variables = 16). Carroll, in his desire to determine whether there is empirical support for the structure comprising the most salient aspects (i.e., Structure 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.CHF constrains 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. Factor-analytic studies reviewed next were either (1) designed as per the CHC framework, (2) designed as per the Carroll and/or Caroll-Horn-Gf-Gc models, or (3) they 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 normative 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-
### TABLE 8.2. Comparison of Cattell-Horn and Carroll Theories of Human Cognitive Abilities

<table>
<thead>
<tr>
<th>Cattell-Horn</th>
<th>Carroll Theory</th>
<th>General intelligence (g)</th>
<th>No</th>
<th>Yes</th>
<th>g (Carroll) vs. non-g (Cattell-Horn).</th>
</tr>
</thead>
<tbody>
<tr>
<td>GT-Gc theory</td>
<td>Stratum theory</td>
<td>Salient similarities and differences</td>
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<td></td>
</tr>
</tbody>
</table>

- **Fluid reasoning (Gi)**: Fluid intelligence (Gi).
  - Similar, with the exception that Carroll (1993 and Chapter 4, this volume) included reading and writing as narrow abilities under Gs. Horn (Horn & Noll, 1997; Horn & Masunaga, 2000) does not include reading and writing under Gs. Horn (1998) previously suggested a possible broad “language use” ability separate from Gs. Carroll (2003) subsequently noted a similar “language” factor in need of further research.

- **Accretion knowledge (Gc)**: Crystallized intelligence (Gc).

- **Short-term apprehension and retrieval abilities (SAR)**: General memory and learning (Gy).
  - Similar. 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. 462). In contrast, Horn’s S-A-R 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 TSI/Gln.

- **Visual processing (Gv)**: Broad visual perception (Gv).
  - Similar.

- **Auditory processing (Ga)**: Broad auditory perception (Ga).
  - Similar.

- **Tertiary storage and retrieval (TSR/Gln)**: Broad retrieval ability (Gd).
  - Similar. 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 speed (Gs).
  - Similar. Horn’s CDS (Horn & Masunaga, 2000) appears to be defined as a more narrow ability (quick or correct answers to nonverbal tasks). Carroll’s (1993) definition appears slightly broader (decision or reaction time as measured by reaction time paradigms).

- **Correct decision speed (CDS)**: Processing speed (RT decisions speed) (Gs).
  - Horn (Horn & Noll, 1997; Horn & Masunaga, 2000) recognizes Gs 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 Gs (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 generalization 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 **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 characteristics (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 (Qk):** Ability to inductively (I) and/or deductively (Rg) reason with concepts involving mathematical relations and properties.

**Figuirable reasoning (F):** 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 (Gk):** “Can be thought of as the intelligence of the culture that is incorporated by individuals through a process of accretion” (Horn, 1998, p. 443). Gk 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. Gk 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 (words, 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 (Kv):** Range of general stored knowledge (primarily verbal).

**Information about culture (Kc):** 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 (FL):** Similar to LD, but for a foreign language.

**Foreign-language aptitude (IA):** Rate and ease of learning a new language.
TABLE 8.3. (continued)

General (domain-specific) knowledge (Gk): An individual's breadth and depth of acquired knowledge in specialized (domain-specific) domains that typically do not represent the general universal experiences of individuals in a culture (Gc). Gk reflects deep, specialized knowledge domains developed through intensive systematic practice and training (over an extended period of time), and the maintenance of the acquired knowledge base through 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 (KS): 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 (AS): 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 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.

Visualizaton (V2): 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 responding to 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 decrement 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 form and form a single percept.

Flexibility of closure (CF): Ability to identify a visual figure or pattern embedded in a complex, distracting, or disorganized 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., patterns 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.

TABLE 8.3. (continued)

Perceptual illusions (II): 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 stimulus). May be best thought of as a person's "response tendency" to resist perceptual illusions.

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

Imageability (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" (Stanovich, 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 (Gastaffson & Udenhout, 1996). The Ga domain encompasses a wide range of abilities involved in discriminating patterns in sounds and musical structure (often under background noise and/or during distracting 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 (Ge), Ga abilities do not require the comprehension of language (Ge).

Phonemic 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, tone patterns, and voices.

General sound discrimination (U1): Ability to discriminate tones, tone patterns, or musical materials with regard to their fundamental attributes (pitch, intensity, duration, and rhythm).

Timetemporal 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 Stanovich (2000), UK may represent the first recognition of the ability (Stanovich & Hors, 1983) that is now interpreted as working memory (MW).

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

Maintaining and judging rhythms (UR): Ability to recognize and maintain a musical beat.

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

Sound frequency discrimination (US): 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 (GSN): 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.

(continued)
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. It is largely recognized as the mind's "scratchpad" and consists of up to four subcomponents. The phonological loop processes auditory-linguistic information, the visuo-spatial sketchpad the visual-spatial data, the central executive functions coordinates and manages the working memory. The component most recently added to the model is the epicritic/supercodifying (Kanwisher, 1997). More broadly, it may be considered imagining problems dealing with a function or change in function of objects and/or identifying methods to address the problems (Royer, 1973).

The recognition of the existence of a problem.

Originality-creativity (PO): Ability to rapidly produce unusual, original, clever, divergent, or uncommon responses (expressions, interpretations), or to effectively produce new solutions to given problems, or to identify new solutions to given problems. It is the current CHC task used to assess the individual's ability to think in a large number of different responses.

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

Cognitive Processing Speed (GS): 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 automated elementary cognitive processes.

Perceptual speed (PS): 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 & CanCianco, 2000; Ackerman & Kanfer, 1993; see chapter text) suggests that PS 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 (Ss): Ability to scan, compare, and look up visual stimuli.
3. Memory (Ps): Ability to perform visual-perceptual speed tasks that place significant demands on immediate short-term memory.
4. Complex (Ps): Ability to perform complex tasks that impose additional cognitive demands, such as spatial visualization, estimating and interpolating, and heightened memory span loads.

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

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

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

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 WP.

Decision/reaction time or speed (Gs): 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) or to cognitive processes.

Simple reaction time (Rs): Reaction time (ms) recorded to the onset of a single stimulus (visual or auditory) that is presented at a particular point of time. Rs1 is frequently divided into phases of decision time (Rs2) and movement time (MT). The time to decide (Rs1) is relatively short (and the fingers leaves from the response button to another button where the response is physically made) and recorded for reaction time (Rs2).

Choice reaction time (Rs): Reaction time (ms) to the onset of one of two or more alternative stimuli, depending on which alternative is signaled. Similar to Rs1, can be decomposed into DT and MT. A frequently used experimental method for measuring Rs2 is the Hick paradigm.

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

Mental comparison speed (Rs): Reaction time (ms) when stimuli must be compared for a particular characteristic or attribute.
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 (F3):** The ability to exert muscular force to move (push, lift, pull) a relatively heavy or immobile object.

**Multilimb coordination (F6):** The ability to make quick specific or discrete motor movements of the arms or legs (measured after the movement is initiated). Accuracy is not important.

**Finger dexterity (F2):** The ability to make precisely coordinated movements of the fingers (with or without the manipulation of objects).

**Manual dexterity (F1):** Ability to make precisely coordinated movements of a hand, or a hand and the attached arm.

**Arm-hand steadiness (F7):** The ability to precisely and skillfully coordinate arm-hand positioning in space.

**Control precision (F8):** 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).

**Aming (A1):** The ability to precisely and fluently execute a sequence of eye-hand coordination movements for positioning purposes.

**Gross body equilibrium (F4):** 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 (Gt):** 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).

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**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 latter narrow ability domains (F and G) factor codes (e.g., R4), as well as most of the broad ability factor codes (e.g., Gf, Gc) 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), Cattell (1982), Eysenck et al. (1979), Flanagan and Quaintance (1994), and Sternberg (1994). An ongoing effort to refine the CHC definitions of abilities can be found in the form of the Carroll-Irons-Carroll (CIC) Definition Project (http://www.sas.upenn.edu/~benedic/).
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 found in a large sample of 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 (McGregor & Woodcock, 2001) reported a CFA-based model of 50 test variables from ages 6 through late adulthood. Support was found for a model consisting of a higher-order factor that subsumed the broad abilities of Gf, Gc, Gv, Ga, Gsm, Glr, Gs, Gw, 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 & McGregor, 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 single general ability and seven broader-factor-based CHC factors (Gf, Gv, Gs, Glr, Gc, Ga, Gsm, Gq), our analyses supported the invariance of the WJ III COG and CHC theoretical frameworks 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 to 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 be the visibleness of the 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 & Jenson, 1929) 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 assumes that the near-zero 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-SI 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 models of intelligence via-a-vis-the model comparison statistics provided by structural equation modeling (SEM) methods.

Brieﬂy, Carroll (2003) concluded that "researchers who are interested in the 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 highly correlated with 1 of g, 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, Gv, Gs, Glr, Gc, Ga, Gsm, Gq, and language (composed of reading and writing tests, also known as Gw).

The most recent morphing of the long line of Stanford-Binet Intelligence Scales (the SB; Roid, 2003) was accomplished 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; also see Roid, 2002, pp. 125-130), and a review of the CHC-organized cross validation of 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 (Gm), and Verbal Processing (Gv). Not measured are the broad abilities of Gw, Ga, Glr, and Gs. CFA reported in the SB-5 manual indicates that the five-factor model (Gf, Gq, Gs, Gc, Gv) was the most plausible model when compared to the 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, & Dermen, 1976) and CFA supported a model that included the broad abilities of Gf, Gc, Gm, (SAR), Gv, Glr, and Gs. The authors also note that 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 commanding 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: Processing Speed, Gc (Verbal Comprehension), and Gv (Perceptual Organization). Tulsky and Price’s Visual Memory factor could be classified as Gm (MM). The factor Tulsky and Price interpreted as Auditory Memory was defined by salient loadings from the WMS-III Logical Memory 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 Gf (i.e., MM, MA, Mo). 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 the Working Memory (Gm-MW).

An alternative intercorrelation of the Working Memory factor could be Numerical Fluency (Gm-N), due to the common use of numerals in all tasks (e.g., D-I, 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 Battery of Adaptive Intelligence, WAIS (BABI), as J 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 Neu-Turn, s, and Briggs (2000) BAB study. Although Tirre and Field reported 13 different types of factors across all studies, only those factors replicated at least twice across all groups. These included g (General Cognitive Ability), Gp (Perceptual Motor Speed), Gs-P (Clerical Speed), Gf (Reasoning), Gc (Verbal), and Glr (Numbers). These findings are consistent with additional Gt-type factors emerged and were defined by slightly different combinations of tests in the different analyses. What Tirre and Field labeled as “Early” could be a Gm “level” factor defined primarily by the combination of Associative Memory (MA) and Mechanical Memory (MM) measures. In contrast, their “Creative” 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 the CHC theory.

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In a study of 179 adults, Roberts, Pallier, and Stankow (1996) used EFA with a collection of 23 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, Gv, Gom (SAR), Gw, Go, 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 other studies that used some of the same measures, as well as measures of tactile and kinesthetic abilities, Roberts, Stankow, 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, Gom (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 relation 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” (FM) components of Gf when viewed through a CHC lens.

Reed and McCallum (1995) presented the results of an EFA for 104 elementary school children who had been administered 18 tests from the Gf-Gc-ccentered 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, Gc (p), Gom (MA), Gc, Ga (PC), and Gsm (MS). McGhee and Liberman (1994) also used EFA methods to investigate the dimensionality of 18 measures selected from a variety of psychodiagnostic batteries. In a small sample of 50 second-grade students, six distinct CHC cognitive factors were identified: Gv (MV), Gom (MS), Gv (SR), Gc, Gv (PA), and Gq (KM). In addition, two tests requiring the drawing of designs represented a visual-motor factor that corresponds to abilities within Carroll’s (1993) domain of Broadly-Defined Psychomotor Abilities. Narrow Visual Memory (WJ-R) tests were also submitted to an EFA together with 12 tests from the Detroit Tests of Learning Aptitude—Adult in a sample (n = 50) of elderly adults. In ABC Number Recall and Word Order could be interpreted as Memory Span (Gsm-MS) rather than Sequential Processing.

Davis and 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 subjects in sixth, seventh, and eighth grades. Although a variety of specific hypotheses were tested at the stratum 1 (narrowability) level, support was found at the broad-factor level for the CHC abilities of Gf, Gc, Gv (MV and CS), Ga (PC), Gsm (MS), Gom (MA), Gs (P), and Gw. 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).

In recent studies, the authors 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, McGraw and Knopik (1998) administered 18 WJ III tests and 12 tests from the Das–Naglieri CAS (Naglieri & Das, 1997), Kensch, Kramers, and Flanagan’s (2001) CFA provided support for the broad factors of Gf, Gc, Gv, Gs (P), Gom (MA), Gs, and Gw.

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 (1996) 1995 EFA of 8 KAIT and 13 KABC 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 Gw and Gq. Two different visual factors were identified and were labeled Simultaneous-Average on 12 Broad Visualizations 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, 38; KAIT Memory for Briefly-presented Information, 50; Memory span Gm; WJ-MV; KAIT Memory for Block Designs, 44, K-AABC Gestalt Closure, 42, K-ABC Hand Movements, 40) factors. Finally, the KAIT and the K-ABC Number Recall and Word Order could be interpreted as Memory Span (Gsm-MS) rather than Sequential Processing.

Empirical Evaluations: Summary and Conclusions

Collectively, the large- and small-scale 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, Gs, Gom, Gs, Gv, Gw, and Gw 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, Stankow (2000) reached a similar conclusion (with the exception that he did not include Gw 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 theories and recent factor-analytic research, will contribute to the ongoing search for increasingly satisfactory approximate models 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 and external considerations 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 investigatory) extensions (Stankow, 2000). CHC model extensions have focused on the broad abilities of general knowledge (Gk), social abilities (Gs), and physical and task-oriented abilities (Gt), and three separate broad ability Gs, general cognitive speed; Gw, decision reaction time; and Gw, psychomotor speed).
To properly evaluate the relative merits of the g versus no-g positions would require extensive reading of the voluminous g literature. Fewer than three books or major papers (Brand, 1996; Jensen, 1996; 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 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). 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 & Masuna, 2000) typically presents two lines of evidence against the “g as a unitary process” position. Structurally, Horn and Masuna (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 & Masuna, 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 intelligence 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 diagnostic structure are different” (Horn & Masuna, 2000, p. 139). That is, the broad CHC abilities demonstrate differential relations with (1) different outcome criteria (e.g., in the academic domain, see Evans, Floyd, McGrew, & Leforge, 2002; Floyd, Evans, & McGrew, 2003; McGrew, 1995; McGrew & Hessler, 1993; McGrew & Heflinger, 2003; McGrew & Trowbridge, 2000); (2) 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 & Masuna, 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 factor V in his three-stratum theory, there is a specific state or substrate (“e.g., structured patterns of potential labor in neurology”; 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 substrates from that individual. Carroll (2003) further argued that the different factors he reported (Carroll, 1993) do represent the same construct, given the underlying structure 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 is discovered to account for a set of intercorrelations does not necessarily relate to special characteristics of the variables involved in the correlation matrix; it relates only to characteristics of the 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 two 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 Gc, Gf, and Gd, as provided in the Nyborg chapter...in the sense Gc and Gf could be independently established factor patterns, (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 Gc or Gf. These items of knowledge are in some way special—classified under Gf or Gd (or some combination of these). It appears that a human being becomes a “member of society” only by acquiring aspects of specifc knowledge that are not 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 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). 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 (1996; Kyllonen & Christal, 1990), based on very high latent factor correlations (.80 to the mid-.90s) be-
between measures of MW and Gf in a variety of adult samples. Attempts to understand the relationship 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 (Gf; Engle, Cantor, & Carullo, 1992; Just & Carpenter, 1992), reading and mathematics (Grw and Gf; Hitch, Towse, & Hutton, 2001; Leather & Henry, 1994), reasoning or general intelligence (Gf and g; Ackerman, Beier, & Boyle, 2002; Conway, Cowan, Bunting, Thwaites, & Minkoff, 2002; Engle, Tuholski, Laughlin, & Conway, 1999; Fry & Hale, 1996, 2000; Kyllonen & Christal, 1990; Suls, Oberauer, Wittmann, Wilhelm, & Schulze, 2002), and long-term memory performance (Park et al., 1996; Suls et al., 2002).

The theoretical explanations for the consistently strong MW → Gf or Gc criterion relations differ primarily in terms of the different cognitive resources proposed to underlie MW performance (Lohnan, 2000). More specifically, multiple-resource and resource-sharing models have been proposed (Baysal, 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 (Baysal 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 (Lohnan, 2000, p. 325). A detailed treatment of the different theoretical explanations for working memory is beyond the scope of this chapter and is not necessary for 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 Gc.

In the causal models portrayed in Figure 8.2, MW demonstrates a significant effect on all dependent variables (primarily Gf or g). With the exception of the SuI and colleagues (2002) models (Figures 8.2d and 8.2e), the strength of the MW → Gf/g (0.38 to 0.60) relations are lower than those reported by Kyllonen and Christal (1990). The weakest MW → Gf relationship (0.38) 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 SuI and colleagues models, MW collectively exerts a strong influence on g (MW1 = 0.65; MW2 = 0.40, Figure 8.2d) and Gf (MW1 = 0.70; MW2 = 0.24, 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 Gc). 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, Gl, Gs, and Gv; McGrew & Woodcock, 2001). 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 separate 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 2,000 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). 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 parameter 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 Table 8.4.
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)

<table>
<thead>
<tr>
<th>Age group (in years)</th>
<th>% g variance explained</th>
<th>MW to g path</th>
<th>Gs to g path</th>
<th>Gs to total direct + indirect effects</th>
<th>MS to MW path</th>
<th>Gs to MW path</th>
<th>Select model fit statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-8</td>
<td>86%</td>
<td>.93</td>
<td>.79</td>
<td>.44</td>
<td>.63</td>
<td>.46</td>
<td>.88</td>
</tr>
<tr>
<td>9-13</td>
<td>80%</td>
<td>.90</td>
<td>.60</td>
<td>.46</td>
<td>.70</td>
<td>.39</td>
<td>.94</td>
</tr>
<tr>
<td>14-19</td>
<td>76%</td>
<td>.82</td>
<td>.61</td>
<td>.49</td>
<td>.80</td>
<td>.27</td>
<td>.93</td>
</tr>
<tr>
<td>20-39</td>
<td>80%</td>
<td>.83</td>
<td>.67</td>
<td>.50</td>
<td>.80</td>
<td>.30</td>
<td>.90</td>
</tr>
<tr>
<td>40-90+</td>
<td>84%</td>
<td>.73</td>
<td>.61</td>
<td>.43</td>
<td>.63</td>
<td>.43</td>
<td>.88</td>
</tr>
</tbody>
</table>

*aGFI, goodness-of-fit index;  
*bAGFI, adjusted goodness-of-fit index;  
*cCFI, normalized comparative fit index;  
*dRMSEA, root-mean-square error of approximation;  
*eRMSEA low-high, 95% confidence band for lower and upper limits of RMSEA.
THEORETICAL PERSPECTIVES

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, Gf, Gv, Gv). The trend for the MW → g path to decrease with increases in age (ages 19, 20, 21, 22, and 23) 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 19), and a much more substantial effect at middle age and beyond (12). These developmental trends suggest the hypothesis that during adolescence, the individual's formal 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 → Gs). 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) 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 (i.e., 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 ability . . . 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 (Sui 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/react 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 understanding our increasing 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 performance. According to Sui 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. Varying the 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 model 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 score) 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 individual and occupational outcomes), historically have not met with consistent success. In his American Psychological Association presidential address, McNemar (1966) concluded that "the work of the multi-test batteries as differential predictors of achievement in school has not been demonstrated" (p. 875). Cronbach and Snow (1977) and a 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 preeminence 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 generally met 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 initial full scale IQ score in the applied practice of intelligence test interpretation. However, Daniel (2000) believes that these critics have probably "overstated" their case and give some of the techniques they have used in their research.22

Despite the "hall 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, & Kameenui, 1993; Kavale, 1998; Kavale, 1999; Kavale, 2000; Kavale et al., 1995; Stone, 1999; Stone et al., 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 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 profiles 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 (viz., simply predicting). The key advantage of the SEM method is that it allows for the simultaneous inclusion of causal paths (effects) from a latent g factor, plus specific paths, to 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 Carrell-Horn Gf-Gc-based WJ-R norm data, we (McGrew et al., 1997;
Vanderwood, McGrew, Flanagan, & Keith, 2004) and, depending on the age level (for g + specific abilities), grade-differentiated samples from grades 1–12, that the CHC abilities of Ga, Ge, 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 Ge (.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 (2004) applied the 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 abilities (e.g., WJ-R subtest scores) can significantly affect causal effects on reading and math achievement.

CONCLUSIONS AND CAVEATS

“These are exciting times for those involved in research, development, and the use of intelligence tests batteries” (McGrew & Flanagan, 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 variations thereof) 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) conclusions to the future research on the domain of cognitive mental speed, where research now suggests a domain characterized by a complex hierarchical structure with a g factor speeded by the same g factor across all domains.”

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 cannot capture the complexities of the real world which they purport to represent. At best, they can provide an approximation of the reality that has some substantive meaning and some utility.
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 narrowly abilities within that domain. With the foundational CHC structure serving as a working map, researchers can return to previously ignored 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 the 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, 1999).

Second, CHC theory needs to move beyond the mere description and cataloging of human abilities to provide multilevel 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; Cocchi, Logie, DellaSala, MacPherson, & Baddeley, 2002; Conway et al., 2001; Daniel & Merikle, 1996; Fry & Hale, 2000; Kylloinen, 1996; Lohman, 2001; Miyake, Friedman, Retterer, Shah, & Hegarty, 2001; Oberauer, Siu, Wilhelm, & Voss, 2003; Paas, Renkl, & Sweller, 2003; Paas, Tuovinen, Tabbers, & VanGerven, 2003) has produced promising models for understanding the dynamic interaction between 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; Siu et al., 2002) is a promising lens through which to view CHC theory. Older and less-used multivariate statistics procedures, such as multidimensional scaling (MDS), need to be pulled from psychometricians' closets to allow for the simultaneous examination of content (factors), processes, and prior knowledge complexity. In addition, the promising "behind 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 g. Finally, it is time for the CHC taxonomy to go "back to the future" and revisit the original conceptualization of aptitude, 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 proficiency, 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—potentiality that enables the development or production, given specified conditions, of some more advanced performance" (Corno et al., 2002, p. 3). Aptitudes represent the multivariate reper- tories of a learner's degree of readiness (pro- pensions) to learn and to perform well in general and domain-specific learning set- tings. As such, a person's aptitudes must include, along with cognitive and achievement abilities, affective and conative characteris- tics. Intelligence scholars and applied assessment personnel are urged to investigate the contemporary theories of 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 extension of a cornerstone of a model of human aptitude.31

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, 1996) list between seven and nine abilities, and also provide slightly different names for the Three Zone PMAs.

3. The 1977 WJ was, at the time, the only individually administered intelligence test battery to include miniature "grading" tasks. The possibility of revising these tests, or developing new tests, that reflected the dynamic assessment approach espoused in Vygotsky's (1978) zone of proximal development (Stemberg & Kaufman, 1998) resulted in the inclu-
review for a number of journals. His approach had clearly evolved to one of first ob-
taining results from his EFA-AL approach (as described in Chapter 3 of his 1993 book; see Figure 8.11a) and then using those results as the starting point for CFA refinement and model testing (as described in Carroll, 2003; see Figure 8.11b).

9. The complete process used to classify all tests from all major intelligence batteries at struc-
turally comparable in McGrew (1997).

10. A so-called "tripping point" is the "moment of critical mass, the threshold, the boiling point" (Glanum, 1999, p. 12) where a movement that has been building over time, generally in small groups and networks, be-
gins to influence a much wider audience.

11. Carroll recognized the CHC umbrella ter-
minology in his last publication (2003), al-
though he also was a bit puzzled over the de-
tails of the origin of the so-called CHC (Carroll-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 con-
sultant 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 wedding in Fairbanks, Alaska, on May 26, 2003), Carroll recognized the prac-
tical rational for the CHC umbrella term, but was planning to make it clear in the revision of his 1997 CCA chaptar that although the CHC umbrella term might make practical sense, he felt strongly that the human cognitive abilities consisted of at least three strands and that, in contrast to Horn's position, that g ex-
sists. 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 as-
pects of the structure of human cognitive abilities. Chapter 4 of the present volume is a re-
print of his chapter in the 1997 CCA 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, neuropsychological, outcome criticism) published during the past decade.

13. See note 8.

14. Whereas indicated, from this point on in this chapter, the factor names as re-
ported by the original investigators are in pa-
renchases. The factor names/CHC abbrevia-
tions 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, 1993 analysis are presented in McGrew and Flanagan (1998).

17. The factor interpretations presented here are based on my interpretation of the CHCce and Liebman results. They used similar GL-Gc terminology to provide slightly different, but very similar, factor in-
terpretations.

18. The Buckhalt et al. (2001) Gl factor was de-
fined primarily by measures of Glc, but also had a number of significant loadings from tests that measure Gv abilities. I have repe-
etly seen the same type of factor in EFA's 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 re-
ported here.

20. See Daniel (2000) for a discussion of the vari-
ous issues involved in calculating practical composite IQ scores from intelligence batter-
yes composed of different measures.

21. Another typical description of information-
processing models with modalities as the 

22. For readability purposes, the manifest vari-
able and certain other latent factors (age fac-
tors) were removed from all figures. In ad-
dition, based on a reading of the description of the variables used in each study, I changed the original latent factor names in accor-
dance with CHC theory as described in this chapter. These interpretations do not neces-
sarily reflect the interpretations of the au-
thors of the original published studies.

23. Hornburg and Ingle (2002) and Park and colleagues (1996) have reported similar causal models with modality performance as the dependent latent variable. In these stud-
es, the MW direct causal pathway was .30 and .49. In the Hornburg and Ingle 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 latest factors were selected based on the principles of (1) providing at least two qualitatively different narrow-ability indicators for each CHC factor; (2) using tests that were not factorially complex as determined from CFA studies (McGrew & Woodcock, 2003); 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 analy-
sis was to explore the relations between basic information-processing constructs (Gs and Gv) and g, no effort was made to "weak" the measurement models in each sample in search of slightly better-fitting models. The same configurally invariant measurement model was used across all five samples.

26. In the WJ III, the combination of Gs and MW (GcGv) is also measured, and is quantified as "Cognitive Efficiency" (McGrew & Woodcock, 2001).

27. A nice summary of the issues involved in in-
telligence 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 mod-
els 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 

30. An example of this concern is the use of the generic term "intelligence" when discussing construct validity, which can mean different things to different people. For example, construct validity, in a more broad sense, includes not only the traditional definition but also the construct's relationships to other constructs (e.g., academic achievement, social skills, etc.).

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CONTEMPORARY
INTELLECTUAL ASSESSMENT
Theories, Tests, and Issues
SECOND EDITION
Edited by
DAWN P. FLANAGAN
PATTI L. HARRISON
2005
THE GUILFORD PRESS
New York London