Please use the following citation when referencing this work:

Woodcock, R. W., Maricle, D. E., Miller, D. C., & McGill, R. J. (2018). Functional Cattell-horn-Carroll nomenclature for practical applications. In D. P. Flanagan & E. M. McDonough (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (4th ed., pp. 901-911). New York: Guilford Press.

Functional Cattell-Horn-Carroll Nomenclature for Practical Applications

Richard W. Woodcock

Denise E. Maricle

Texas Woman's University

Daniel C. Miller

Woodcock Institute for the Advancement of Neurocognitive Research and Applied Practice

Ryan J. McGill

William & Mary

Correspondence for this chapter should be addressed to:
Dr. Denise Maricle
Department of Psychology and Philosophy
Texas Woman's University
P.O. Box 425470
Denton, Texas 76204
dmaricle@twu.edu

Functional Cattell-Horn-Carroll Nomenclature for Practical Applications

The purpose of this chapter is to review the evolution of Cattell-Horn-Carroll (CHC) theory, in an effort to examine the state of the state of the art in this dominant theory defining the structure of cognitive abilities. The nomenclature associated with CHC theory has become more complex as scholars have elaborated upon the theory, introducing their additions and revisions to the taxonomy. With the publication of the Woodcock-Johnson IV (WJ IV), the preeminent instrument operationalizing CHC theory, change was seen in the conceptualization of CHC theory. In particular, the shift seemed to be toward a more “scientific” and less “functional” or clinician/consumer-friendly CHC nomenclature. This scientific taxonomy is exemplified by what is known as the *CHC periodic table of human abilities* (McGrew, LaForte, & Schrank, 2014; Schneider & McGrew, 2012). The application of CHC theory to measures of cognitive abilities, and the wide acceptance of the theory in research and clinical practice, have given rise to a specialized vocabulary (i.e., nomenclature or taxonomy) that can be difficult for consumers of the information, such as parents, clients, or educators, to understand. Scientific taxonomies are needed to provide precision and to guide scientific development, but more functional or user-friendly nomenclature would benefit consumers. Given recent changes in CHC theory, it seems appropriate to summarize the history of the theory, as well as to discuss current proposals for the continued evolution of the theory being presented by various factions within CHC. The chapter concludes with a description and discussion of a more functional and clinician/consumer-friendly CHC nomenclature.

HISTORICAL PRECEDENTS TO CHC THEORY

Spearman's Two-Factor Theory

Inspired by the statistical developments of his cousin Karl Pearson, British statistician Charles Spearman proposed the first unified theory of cognitive abilities with the 1904 publication of his paper "'General Intelligence', Objectively Determined and Measured." Although Spearman did not label his theory, it is generally referred to in the contemporary literature as *g* theory. Spearman (1904) administered a battery of assessments to a sample of 60 school-aged children in a small village in England. The tests measured subjects such as the classics, French, English, math, vocal pitch, and sound discrimination. He determined that all of the measures tended to correlate—a phenomenon later referred to as *positive manifold* (Thurstone, 1947). Spearman arranged all of the coefficients between the tests into a matrix that he then analyzed, using a primitive form of factor analysis called the method of *tetrad differences*. In his analysis, he found that *62.9%* of the total variance between all of the tests was accounted for by a single factor, which he identified as a general factor or *g*. The remaining *37.1%* of variance was attributed to specific factors unique to the individual tests themselves, which Spearman labeled *s*.

Spearman postulated that all tests of cognitive ability are composed of some form of *g* variance—an observation he referred to as the "indifference of the indicator" (Spearman, 1927, p. 197). However, he appeared to remain ambivalent about the exact nature of *s*, whose influence he stated was largely negated by the combination of individual test scores into larger composites.

Despite criticism, he resisted the notion of including additional common factors in his model because he felt it would open the door for the inclusion of an infinite number of hypothesized subordinate factors. By the end of his career, however, he acknowledged that cognitive ability may be better represented by a second-order *g* factor, with an underdetermined number of first-order common factors representing more discrete cognitive skills (Spearman & Jones, 1959).

The Rise of Multiple-Factor Theories

One of Spearman's critics was Edward L. Thorndike, a psychologist at Columbia University. Thorndike developed and facilitated the administration of a test to 63 primary and secondary school students that purported to measure several psychoeducational abilities, such as sensory discrimination, quantitative reasoning, and vocabulary development. After reviewing correlational data, he and his colleagues concluded that "there is nothing whatsoever common to all mental functions, or even half of them" (Thorndike, Lay, & Dean, 1909, p. 368). Thorndike rejected the notion of a general intelligence factor in favor of a model that emphasized multiple faculties of the mind.

Although Spearman spent the latter part of his career defending his theory from researchers like Thorndike, advances in research methodology and statistical techniques allowed for the discovery of group abilities in cognitive assessment data. Spearman eventually acknowledged these findings when specific cognitive tasks were found to load on group factors subordinate to *g*. These discoveries helped pave the way for the development of more empirically derived theories of mental ability.

L.L. Thurstone (1938) developed a model of mental ability derived from a statistical technique that allowed for factors to be extracted from an extant dataset---a method known as *factor analysis*. Using data from a battery of 56 mental tests that were administered to 240 college students, he extracted seven factors that he described as visual-spatial, perception of visual detail, numerical, verbal logic, verbal words, memory, and induction. Thurstone called these factors *primary mental abilities*, and this term soon became associated with his model of intelligence. Thurstone eventually reconfigured his model to account for eight primary abilities. The influence of Thurstone's work on the modern-day understanding of the structure of human cognitive abilities cannot be underestimated, as many of the group factors that he identified served as the foundation for subsequent models of intelligence.

Thurstone's initial reluctance to acknowledge a general factor may have been an artifact of the methods he utilized to identify his group factors. Thurstone used rotation techniques in his factor analyses that left various broad abilities orthogonal (not correlated) to each other. With this method, it was almost impossible for a general factor to be derived because little common variance in the factors could be extracted. Although Thurstone later accepted the existence of a general factor, and subsequent research using oblique rotations indicated that his broad abilities were correlated (Jensen, 1998), he stated that the use of a single score to estimate overall mental ability was inadequate for clinical decision making; he encouraged the synthesis of an individual's profile of scores across several measures of cognitive functioning to determine individual cognitive strengths and weaknesses.

The Emergence of Gf-Gc Theory and the Fluid-Crystallized Model of Intelligence

A dichotomous model of intellectual ability, the *fluid-crystallized model* or Gf-Gc theory, was proposed by Raymond Cattell in the early 1940s. In a commentary discussing issues unresolved in the measurement of adult intelligence, Cattell (1943) postulated that cognitive ability was best represented by two general factors that he identified as a fluid intelligence (Gf) and crystallized intelligence (Gc). Cattell described fluid intelligence as a general facility in reasoning, wherein prior knowledge cannot be used to solve problems, and crystallized intelligence as the storage, retrieval, and use of prior knowledge. Two decades later, Cattell (1963) conducted the first experimental analysis of the theory by administering a series of nine cognitive tasks to a sample of 277 school-aged individuals and then subjecting the results to a factor analysis. His results indicated that each of the tasks primarily loaded on one of the two factors.

Cattell chose not to include a general factor in his model, despite the fact that he acknowledged that Gf and Gc were highly correlated and that a third-order factor solution was tenable. Rather, Cattell posited that *g* operated largely through Gf, and he proposed *investment theory* as a vehicle for describing the interaction between Gf and Gc. According to Cattell (1987), fluid ability serves as a limiting factor in how much information individuals can acquire from the environment. Therefore, learning is a function of the interaction between inherited levels of fluid ability and interpersonal metacognitive factors (motivation, drive, personality) that regulate how much that fluid ability is invested by the individual within the environment. The product of that investment is later expressed in the form of developed crystallized ability. Cattell proposed that this interaction helped explain why Gf and Gc were so highly correlated.

The first replication of Gf-Gc theory was conducted by John Horn in his doctoral dissertation supervised by Cattell at the University of Illinois. Horn (1965) administered 31 cognitive and personality tasks to a sample of 297 adults. He extracted several second-order factors from the data, which he identified as fluid intelligence (Gf), crystallized intelligence (Gc), general visualization (Gv), general speediness (Gs), facility (a forerunner of long-term storage and retrieval), carefulness (general cognitive accuracy), premsia (PRM, literacy and artistic ability), and positive self-image (PSI). Horn then extracted two general factors that he did not identify further. The first general factor was composed of Gf, Gv, Gs, and facility. The second general factor was composed of Gc, Gf, and PSI. From their first joint publication (Horn & Cattell, 1966) through the late 1990s, Horn and Cattell collaborated on a systematic program of research aimed at validating and adding additional second-order factors to the Gf-Gc model. Specifically, Horn (1986) laid out an expansion of Gf-Gc theory designating eight broad abilities that were later modified and used to guide the organization of the WJ-R Tests of Cognitive Ability (Woodcock & Johnson, 1989). By the early 1990s, the Gf-Gc model had expanded to include nine broad second-order abilities: fluid intelligence (Gf), crystallized intelligence (Gc), short-term acquisition (Gsm), visual intelligence (Gv), auditory intelligence (Ga), long-term storage and retrieval (Glr), cognitive processing speed (Gs), correct decision speed (CDS), and quantitative knowledge (Gq). At about this time Woodcock (1990) proposed the additional inclusion of a reading and writing ability factor (Grw).

One of the more consequential discoveries from this Gf-Gc research program has been the demonstration of differential declines in various broad abilities over the course of the human lifespan. In general, it has been demonstrated that Gc tends to increase throughout adulthood, with small declines emerging around age 70 (Ackerman, 1996). Conversely, Gf skills have been shown to peak in early adulthood (i.e., ages 25-30) and then to decline throughout the rest of the lifespan (Verhaeghen & Salthouse, 1997). Using regression growth models, Noll and Horn (1998) estimated that the loss of Gf ability in adulthood was equivalent to 0.5 to 1.0 IQ units per decade. McGrew and Woodcock (2001) later argued that in spite of strong Gf-Gc correlations, such developmental validity evidence demonstrated that Gf and Gc were in fact orthogonal, unrelated abilities.

The Emergence of Hierarchical Models of Intelligence and Carroll's Three-Stratum Model

Phillip Vernon (1950) is credited with articulating the first hierarchical model of cognitive abilities. He posited that a higher-order *g* factor presides over two lower-order factors, which he identified as verbal ability and spatial ability. In his model, the lower-order factors were composed of dozens of narrow abilities, such as psychomotor coordination, attention, fluency, reasoning, and reaction time. Vernon stated that his model was most likely under-identified and went on to hypothesize additional group factors beyond verbal reasoning and spatial thinking, which constituted a more complete model of cognitive ability. Vernon's model was an important reconciliation of Spearman's two-factor model and Thurstone's primary abilities. Additionally, Vernon's model provided empirical support for the verbal-nonverbal dichotomy of cognitive abilities, which was popular as a result of the publication of the Wechsler scales of intelligence (Wechsler, 1949).

A more direct hierarchical test of the nature of cognitive abilities as completed by Gustafsson (1984), who administered a battery of 16 tests to 1,000 sixth-grade students, and then utilized factor analysis to test the fit of several competing models. He reported that the model which best fit the data was a third-order *g* factor that reigned over the three group ability factors. Gustafsson found that the fluid reasoning factor was nearly identical to the third-order general ability factor; this finding which has perpetuated the theory that fluid reasoning is largely a proxy for *g*.

A major breakthrough in applied psychometrics occurred with the publication of John Carroll's (1993) *Human Cognitive Abilities: A Survey of Factor-Analytic Studies.* Carroll assembled a collection of over 400 datasets of factor-analytic studies of cognitive abilities; re-analyzed them utilizing varimax rotations of the principle factor matrices; and followed up with the Schmid-Lieman procedure (Schmid & Lieman, 1957), which further orthogonalized the factors for a more parsimonious interpretation of the resulting factor structure. Carroll concluded that a three-tier model best fit the data. This model later became known as the three-stratum model. In Carroll's model, *g* or general ability was placed at the apex of the model and was labeled stratum III. The next level, or stratum II, included such broad abilities as fluid intelligence (Gf), crystallized intelligence (Gc), general memory and learning (Glm), broad visual perception (Gv), broad auditory perception (Ga), broad retrieval ability (Gr), broad cognitive speediness (Gs), and reaction time/decision speed (Gt). Over 70 narrow cognitive abilities, organized according to their loadings on the broad factors, comprised stratum I.

Carroll's three-stratum model was widely embraced by the scientific community and represented a major paradigm shift in the study of cognitive abilities. The most significant contribution of the model was that it provided the field with a standardized taxonomy to categorize and describe individual cognitive tasks. Many commentators consider Carroll's work the greatest accomplishment in all of applied psychology. Burns (1994, p. 35) stated, for example, "It is simply the finest work of research and scholarship I have read and is destined to be the classic study and reference work of human abilities for decades to come". In the 25 years since its publication, Carroll's work has yet to be seriously challenged.

THE ASCENDANCY OF CHC THEORY

The Birth of CHC Theory

In the late 1900s, Kevin McGrew negotiated the merger of Carroll's three-stratum theory with Cattell and Horn's Gf-Gc theory; he was thus instrumental in the ascendancy of the consolidated CHC model in the field of cognitive assessment. Although the two models were merged, there was not necessarily complete agreement between their creators. Horn refused to accept the validity evidence provided by Carroll for a general ability factor. Horn and Noll (1997) warned that “the problem for the theory of general intelligences is that the factors are not the same from one study to another…. The factors represent different mixture of measures, not one general intelligence” (p. 68). Horn (1986) very clearly argued against a single or unitary factor of intelligence, despite widespread opinion to the contrary. He thought that the evidence conclusively indicated several distinct intellectual abilities, each with differing genetic and environmental determinants, different developmental trajectories or courses of development, and different implications for understanding human cognition and achievement. There were also differences between the originators of the two models regarding the number of broad factors, as well as which broad factors were relevant. For instance, Carroll (2003) concluded that there were data to support 10 broad factors, but argued that Gq (quantitative reasoning) was a narrow ability subsumed under Gf and not a stratum II broad factor. He considered quantitative ability to be “an inexact, unanalyzed popular concept that has no scientific meaning unless it is referred to the structure of the abilities that compose it” (Carroll, 1993, p. 627).

Despite these differences, the two theories were consolidated into one theory with three strata: an optional broad general ability or *g* factor; nine broad-ability factors (crystallized knowledge or Gc, fluid reasoning or Gf, visual-spatial processing or Gv, auditory processing or Ga, short-term memory or Gsm, long-term storage and retrieval or Glr, processing speed or Gs, quantitative knowledge and reasoning or Gq, and reading-writing or Grw); and approximately 89 narrow abilities. In the past several years, Kevin McGrew has become the de facto standard bearer of research with CHC theory, and his classifications of CHC abilities (e.g., McGrew, 2005) have become the standard framework for discussing CHC theory in the empirical literature, although only seven broad CHC abilities constitute the predominant focus of much of the empirical research on human cognitive abilities. While recent work has demonstrated that some of the broad abilities are much more complex than previously thought (McGrew & Evans, 2004), the initial goal of CHC research was to refine the model into a more accurate summary of human cognitive abilities (McGrew, 2009; Wasserman, 2012).

In the years following the consolidation of the Carroll and Cattell-Horn models, CHC theory had a visible impact on the development of new and revised individually administered intelligence tests (Keith & Reynolds, 2010). It has become the dominant interpretive framework for measures of intellectual functioning, and, according to Schneider and McGrew (2012, p. 109), "CHC theory has attained the status as the consensus psychometric model of the structure of human cognitive abilities." Despite the widespread representation of CHC within the cognitive testing landscape, the Woodcock-Johnson series has been the only test battery founded exclusively on CHC theory, and the only contemporary test to assess all of the nine broad-ability factors. Other tests, such as the Stanford-Binet Intelligence Scales, Fifth Edition (Roid, 2003); the Kaufman Assessment Battery for Children-- Second Edition (Kaufman & Kaufman, 2004); the Differential Ability Scales-- Second Edition (Elliot, 2007); and the Wechsler Intelligence Scale for Children – Fifth Edition (WISC-V; Wechsler, 2014), only provide representations of a few broad factors. The broad abilities of fluid reasoning (Gf), crystallized knowledge (Gc), visual-spatial processing (Gv), and short-term memory (Gsm) are widely represented. However, auditory processing (Ga) and long-term storage and retrieval (Glr) are underrepresented within most existing cognitive measures (Flanagan, Ortiz, & Alfonso, 2013).

Beyond CHC

In 2012, Schneider and McGrew proposed changes to CHC theory, which McGrew labeled as going "beyond CHC". McGrew and Schneider posited 16 cognitive domains grouped into five functional areas. The first functional area, cognitive knowledge, is composed of Gc, Grw, Gq, and Gkn. Cognitive operations is the second functional area and is made up of Gf, Glr, Gv, and Ga. The third functional area is cognitive efficiency and control, consisting of Gsm and Gs. The fourth functional area is sensory functions and consists of visual, auditory, and tactile (Gh), kinesthetic (Gk), and olfactory (Go) sensations. The final area is motor functions, consisting of strength, finger dexterity, and manual dexterity (Gp and Gps). Similar to all of the reconceptualizations discussed in this chapter, McGrew and Schneider's reconceptualization of CHC is theoretical; there is no research that currently would support their hypothesized changes, although the authors refer to a synthesis of the research literature in the past 10-15 years as supportive of their proposed changes.

Schneider and McGrew (2012) further reconceptualized the CHC broad and narrow abilities into five expanded domains, labeled motor (Gp), perception (Gv, Gk, Ga, Gh, Go), controlled attention (Gf, Gsm), knowledge (Gc, Gq and Grw with a greater Gkn), and speed (Gps, Gt, Gs, and Glr). Subsequently, McGrew (2016) has suggested that the broad-ability domain of Glr may have been conceptualized incorrectly in the CHC literature since 1997. McGrew posits that Glr should be separated into two broad abilities: Gl (learning efficiency) and Gr (retrieval fluency). Learning efficiency is defined as "the ability to learn, store, and consolidate new information in long-term memory" (McGrew, 2016). Retrieval fluency is defined as the rate and facility with which individuals can generate and regain verbal and nonverbal information or ideas stored in long-term memory (McGrew, 2016). McGrew often refers to his current overview of CHC abilities as CHC model v2.3. Additionally, it has been suggested (e.g., Shneider & McGrew, 2012) that a joint neuropsychological and CHC perspective might be the new frontier for understanding cognitive constructs and assessment of cognitive performance and abilities. For the latest revisions and refinements to CHC theory, see Schneider and McGrew (Chapter 3, this volume).

A joint neuropsychological and CHC perspective has been conceptualized by Miller (2013) and articulated in his integrated school neuropsychology/CHC conceptual model. Miller's model is distinctive, as it uses neuropsychological, neuroanatomical, and neuroassessment research to theorize the model's components. In Miller's conceptual model, tasks are classified according to four broad classifications (basic sensorimotor functions; facilitators and inhibitors; basic cognitive processes; and acquired knowledge), and are then further segmented into second- and third-order classifications that denote the broad and narrow CHC constructs being assessed by various tasks. Miller (2015) and Miller, McGill, and Bauman Johnson (2016) have delineated the neuropsychological applications of the WJ IV, WISC-V, WISC-V Integrated, and Wechsler Individual Achievement Test—Third Edition specifically, as well as in relation to Miller's conceptual model. Further supporting a joint neuropsychological/CHC perspective is work by Flanagan, Alfonso, Ortiz, and Dynda (2010) and Flanagan and colleagues (2013), who present an integrated interpretive framework based on psychometric, neuropsychological, and Lurian perspectives, and provide a neurocognitive demand task analysis of the major test batteries using this framework. Flanagan and colleagues (2010, 2013) posit that specific neuropsychological domains correspond well with eight broad CHC abilities—fluid reasoning (Gf), comprehension–knowledge (Gc), processing speed (Gs), short-term memory (Gsm), long-term storage and retrieval (Glr), quantitative knowledge (Gq), reading and writing ability (Grw), and general knowledge ability (Gkn)—and fit well within a cross-battery conceptual framework.

The WJ IV, published in 2014 (Schrank, McGrew, & Mather, 2014) as a substantial revision of the WJ III, further confuses the issue of the structure of the CHC model. The WJ IV consists of three complementary batteries: the Tests of Cognitive Abilities, the Tests of Achievement, and the Tests of Oral Language. According to the authors of the WJ IV, the nine original CHC factors (Gf, Gc, Gv, Ga, Gsm, Gs, Glr, Gq, and Grw) are still measured, although there are slight reconceptualizations of some factors (such as Gsm, which has been renamed Gwm). However, the factor structure of the WJ IV based on reported factor analyses in the technical manual (McGrew et al., 2014) has recently been questioned (Dombrowski, McGill, & Canivez, 2017). The technical manual reported the results of exploratory cluster, factor, and confirmatory factor analyses. These analyses were conducted "during the early stages of WJ IV data collection" with subsections of the normative group and on the completed normative sample of 7,416 individuals (McGrew et al., 2014, pp. 149– 150). The authors chose a model-generating approach to their analysis of the data, and they note that it was a major component in the multistage structural validity procedures utilized. Three different exploratory methods—cluster analysis, exploratory principal-components analysis, and multidimensional scaling analysis—were applied.

Dombrowski and colleagues (2017) have criticized the exploratory and confirmatory analyses described in the technical manual, noting that significant amounts of the data were imputed; that some analyses were extrapolated; and that the methods chosen for the analyses were not appropriate, incomplete, or less sophisticated. McGrew and colleagues (2014) note that the obtained structural models varied by methodology. In general, two consistent factor structures emerged. The first factor structure consisted of five factors (Gc, Gs, Grw, Gq-Gf, and Gwm). The second consisted of three factors that they labeled auditory–linguistic (Ga, Gc, and select Gwm tasks), visual–figural (Gv, Gf, Glr), and quantitative–numeric (Gq and select Gwm tasks). Confirmatory factor analyses were also conducted, and two factor structures were found that fit the data. From one of these analyses, the three-stratum hierarchical model emerged, including the general or g factor, broad-ability factors, and narrow abilities. From the other, McGrew and colleagues extracted a two-stratum factor structure consisting of the nine broad-ability factors and narrow abilities. Dombrowski and colleagues used the correlation matrices found in the technical manual to conduct several exploratory factor analyses on two age groups (9–13 and 14–19), using the cognitive tests of the WJ IV. Dombrowski and colleagues identified a four-factor solution as having the most parsimonious fit, but from their professional point of view, they suggest that the WJ IV is best viewed primarily as a measure of g, as it accounts for the majority of total and common variance. Such disparate and contradictory findings are confusing and create questions as to which latent theoretical structures should be applied interpretively.

A FUNCTIONAL REFINEMENT OF CHC THEORY

We suggest a more practical reconceptualization of CHC theory and functional nomenclature to describe CHC latent cognitive factors. We refer to this model as the functional CHC model (FCHC; see Figure 32.1). We recommend grouping the cognitive abilities represented by CHC factors into three broad conceptual domains: acquired knowledge, thinking abilities, and cognitive efficiency. Additionally, a review of the CHC literature and research regarding broad and narrow abilities contributing to CHC factors suggests that each broad ability or CHC factor can be reduced to two primary narrow abilities, without loss of significant information needed for clinical utility.

In the F-CHC nomenclature, the first domain, acquired knowledge, consists of comprehension– knowledge (Gc), reading and writing (Grw), and mathematics (Gq). In the extant CHC perspective, comprehension–knowledge (Gc) is composed of four narrow abilities:

language development (LD), listening ability (LS), general verbal information (KO), and lexical knowledge (VL). The F-CHC nomenclature combines LD and LS into an ability called verbal ability (Gc-VA), and KO and VL into an ability called factual knowledge (Gc-K). In the F-CHC nomenclature, the reading and writing ability factor (Grw) is split into two broad abilities, reading (Grw-R) and writing (Grw-W), as these two areas are perceived by most people (including educators) as separate abilities. Reading consists of two abilities, reading skills (Grw-RS) and reading comprehension (Grw-RC); writing consists of writing skills (Grw-WS) and writing composition (Grw-WC). Finally, quantitative knowledge/reasoning (Gq) has been relabeled as mathematics, to better conceptualize the nature of this latent factor. Calculation (Gq-C) and applied math (Gq-AP) are the two primary abilities composing Gq in this reconfiguration.

Within the F-CHC nomenclature, the second domain, thinking abilities, consists of visual–spatial processing (Gv), auditory processing (Ga), learning–memory (Glm), and reasoning (Gr). In current CHC theory, Gv is composed of five narrow abilities: visualization (VZ), closure speed (CS), spatial relations (SR), spatial scanning (SS), and visual memory (VM). Within the F-CHC model of Gv, these five abilities are collapsed into pictorial processing (Gv-PP) and spatial processing (Gv-SP). For auditory processing (Ga), the narrow abilities of speech sound discrimination (US), resistance to auditory stimulus distortion (UR), sound discrimination (U3), and phonetic coding (PC) are reconceptualized as sound discrimination (Ga-SD) and phonetics (Ga-Ph).

Long-term storage and retrieval (Glr) is renamed in F-CHC as learning–memory (Glm), to better reflect the cognitive abilities being measured in this domain. Glr is consistently misinterpreted by clinicians as long-term memory, or long-term retrieval, when in reality it provides measures of learning, memory, and the ability to efficiently and effectively retrieve what has been encoded in memory or learned. In the extant CHC model, Glr has 13 narrow abilities, which are difficult to conceptualize and measure. In the F-CHC reconceptualization of the Glm factor, the two primary abilities are immediate recall (Glm-IR) and memory retrieval (Glm-MR).

Finally, fluid reasoning (Gf) has been renamed as simply reasoning (Gr), to better reflect the skills measured in this domain. The concept of fluid is not really meaningful in any context and historically seems to have been used as a synonym for novel problem solving. In the extant CHC nomenclature, Gf has three narrow abilities: quantitative reasoning (RQ, often misinterpreted as Gq), induction (I), and general sequential reasoning (RG). In the F-CHC nomenclature, the two primary narrow abilities for Gf are contextual reasoning (Gr-CR) and inductive/deductive reasoning (Gr-ID). Contextual reasoning essentially replaces quantitative reasoning. The Number Series subtest on the WJ IV COG would be a good example of a subtest ostensibly measuring quantitative reasoning, but in reality providing a comprehensive measure of contextual reasoning and abstract thinking. Sternberg (1990) has long argued that contextual reasoning and abstract thinking abilities are required in many areas of cognitive functioning, including reading or solving scientific equations.

The third domain, cognitive efficiency, includes conscious memory (Gcm), formerly Gsm/ Gwm, and cognitive processing speed (Gs). Gsm has been a problematic factor within the CHC framework for many years. Initially called short-term memory (Gsm), it was reconceptualized recently in the WJ IV as short-term working memory (Gwm); however, neither term clearly represents what is being measured within this factor. Gsm incorporates memory span (MS), working memory (WM), working memory capacity (MW), and attention/concentration (AC). Within the F-CHC nomenclature, Gsm is renamed conscious memory (Gcm) and is composed of memory span (GcmMS) and working memory (Gcm-WM). As currently conceptualized in CHC theory, processing speed (Gs) has four narrow abilities: perceptual speed (P), attention/concentration (AC), rate of test taking (R9), and number facility (N). In the F-CHC model, processing speed is renamed cognitive processing speed (Gs), and the primary abilities are perceptual speed (Gs-PS) and thinking speed (Gs-TS).

CONCLUSION

The CHC theory of cognitive functioning is theoretical, but has a solid research base and is supported by over 20 years of additional psychometric research. CHC theory has now been applied in some form or another to several contemporary measures of intellectual functioning. As such, it has been referred to as the consensus psychometric/theoretical model guiding interpretation of cognitive ability measures (see, e.g., Schneider & McGrew, 2012). In order for a good theory or model to stand the test of time, it must evolve as new knowledge is gained, while still retaining its foundation or core. For any revision or refinement of the model to be considered valid, it too must be subjected to rigorous research, with each suggested addition, subtraction, or substitution carefully weighed and considered.

The evolutionary advances proposed by McGrew and others, as well as changes in perspective given to current CHC constructs within measures such as the WJ IV and WISC-V, would suggest a need for practitioner’s to re-conceptualize interpretation of CHC latent abilities. A good deal of attention in the WJ IV focuses on cognitive complexity (e.g., constructs that are cognitively complex and difficult to measure; tasks that are cognitively complex and thus measuring more than one latent ability).

CHC theory and its variants have also suffered from “descriptive messiness” of the latent constructs. For example, the construct of short-term memory (Gsm) has always been problematic and not reflective of the breadth and depth of our understanding of memory functions. For the most part, the CHC broad ability of Gsm was referring to short-term memory capacity or short-term working memory capacity, and most tasks measured this latent ability in the auditory domain only. With the advent of the WJ IV, an attempt was made to address the limitations of Gsm—primarily by renaming the factor and calling it Gwm, to better reflect the fact that tasks were measuring short-term working memory capacity. However, there is strong research to suggest that the neurocognitive constructs of short-term memory capacity, short-term working memory capacity, and working memory can be distinguished from each other, as well as, adequately independently measured in both auditory and visual domains. This descriptive messiness has now been extended by McGrew’s concern that Glr (long-term storage and retrieval) has probably been misconstrued for the last 20 years, as well as his view that the importance of Ga (auditory processing) has been underrepresented.

For the average clinician attempting to apply the CHC framework to assessment and interpretation, the complexity of CHC theory and the human cognitive abilities it purports to describe, as well as the use of instruments supposedly measuring these abilities, is often challenging in and of itself. The need to possess in-depth understanding of latent neurocognitive factors, multiple narrow abilities, and variations in how tasks measure both latent abilities and narrow abilities, as well as proposed theoretical advances, can seem overwhelming to the average clinician. Many clinicians already find it difficult to describe and/or explain to clients current conceptualizations of CHC broad and narrow abilities and how they are measured by various tasks, as well as what all these things mean for their or their children’s functioning. The effectiveness of communicating assessment results to consumers (clients, parents, teachers, etc.) is a direct function of the language and vocabulary being used. Our proposed F-CHC nomenclature provides a more parsimonious structure that is consistent with recent research (neuropsychological, cognitive, achievement), more functional for understanding the CHC theoretical constructs, more practical for the average clinician, and more understandable to consumers of the information.

References

Ackerman, P. L. (1996) A theory of adult intellectual development: Process, personality, interests and knowledge. *Intelligence, 22*, 227-257.

Burns, R. B. (1994). Surveying the cognitive terrain. Reviewed work(s): *Human cognitive abilities: A survey of factor-analytic studies* by John B. Carroll. *Educational Researcher, 23* (3), 35-37.

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

Carroll, J. B., (2003). The higher-stratum structure of cognitive abilities: Current evidence supports g and about 10 broad factors. In H. Nyborg (Ed.), *The scientific study of general intelligence: Tribute to Arthur R. Jensen* (pp. 5-21). New York: Pergamon Press.

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

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

Cattell, R. B. (1987). *Intelligence: Its structure, growth, and action*. New York: Elsevier.

Dombrowski, S. C., McGill, R. J., & Canivez, G. L. (2017). Exploratory and hierarchical factor analysis of the WJ-IV Cognitive at school age. *Psychological Assessment*. 29(4), 394-407.

Elliot, C. D. (2007). *Differential Ability Scales – Second Edition*. San Antonio, TX: Harcourt Assessment.

Flanagan, D. P., Alfonso, V.C., S. O., & Dynda, A.M. (2010). Integrating cognitive assessment in school neuropsychological evaluations. In D. C. Miller (Ed.), *Best practices in school neuropsychology: Guidelines for effective practice, assessment, and evidence-based intervention* (pp. 101-140). Hoboken, NJ: Wiley.

Flanagan, D. P., Ortiz, S. O., & Alfonso, V. C., (2013). *Essentials of cross-battery assessment* (3rd ed.). Hoboken, NJ: Wiley.

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

Horn, J. L. (1965) *Fluid and crystallized intelligence: A factor analytic study of structure among primary mental abilities.* Unpublished doctoral dissertation. University of Illinois at Urbana-Champaign (UMI No. AAT 6507113).

Horn, J.L. (1986). Intellectual ability concepts. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (pp. 35-77). Hillsdale, NJ: Erlbaum.

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

Horn, J. L. & Noll, J. G. (1997). Human cognitive abilities: Gf-Gc theory. In D. P. Flanagan, J. L. Genshaft, & P. L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (pp. 53-91). New York: Guilford Press.

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

Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman Assessment Battery for Children-Second Edition.* Circle Pines, MN: American Guidance Service.

Keith, T. Z., & Reynolds, M. R. (2010). Cattell-Horn-Carroll abilities and cognitive tests: What we’ve learned from 20 years of research. *Psychology in the Schools, 47,* 635-650.

McGrew, K. S., (2005). The Cattell-Horn-Carroll theory of cognitive abilities. In D. P. Flanagan & P. L. Harrison (Eds.), *Contemporary intellectual assessment* (2nd ed., pp. 136-181). New York: Guilford Press.

McGrew, K. S. (2009). Editorial: CHC theory and the Human Cognitive Abilities Project: Standing on the shoulders of the giants of psychometric intelligence research [Editorial]. *Intelligence, 37*, 1-10.

McGrew, K. S. (2016). The CHC model of human cognitive abilities--a proposed revision (v2.3): Has Glr been incorrectly conceptualized since 1997? Retrieved from: http://www.iqscorner.com/2016/06/the-chc-model-of-human-cognitive.html.

McGrew, K. S. & Evans, J. (2004). *Internal and external factorial extensions to the Cattell-Horn-Carroll (CHC) theory of cognitive abilities: A review of factor analytic research since Carroll's seminal 1993 treatise.* St. Cloud, MN: Institute for Applied Psychometrics.

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

Miller, D.C. (2013). *Essentials of school neuropsychological assessment* (2nd ed.). Hoboken, NJ: Wiley.

Miller, D.C. (2015). Integration of the WJ IV, WISC V, WISC V Integrated, and WIAT III into a school neuropsychological assessment model. *School Psychology Forum: Research in Practice*, 9(3), 1-18.

Miller, D.C., McGill, R., & Bauman Johnson, W. L. (2016). Neurocognitive applications of the Woodcock-Johnson IV. In D.P. Flanagan & V.C. Alfonso (Eds.), *WJ IV clinical use and* *interpretation: Scientist-practitioner perspectives* (pp. 355-388) London: Academic Press/Elsevier.

Noll, J. G., & Horn, J. L. (1998). Age differences in processes of fluid and crystallized intelligence. In J. J. McArdle & R. W. Woodcock (Eds.), *Human cognitive abilities in theory and practice* (pp. 263-282). Mahwah, NJ: Erlbaum.

Roid, G. H. (2003). *Stanford-Binet Intelligence Scales, Fifth Edition*. Itasca, IL: Riverside.

Schmid, J., & Leiman, J. M. (1957). The development of hierarchical factor solutions. *Psychometrika, 22*, 53-61.

Schneider, W. J., & McGrew, K. S., (2012). The Cattell-Horn-Carroll model of intelligence. In D. P. Flanagan & P. L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues. (*3rd Ed., pp. 99-144). New York: Guilford Press.

Schrank, F. A., McGrew, K. S., & Mather, N. (2014). *Woodcock-Johnson IV*. Rolling Meadows, IL: Riverside.

Spearman, C. (1904). "General intelligence," objectively determined and measured. *American Journal of Psychology*, 15, 201-293. Retrieved from http://psychclassics.yorku.ca/Spearman.

Spearman, C. (1927). *The abilities of man: Their nature and measurement.* New York: Macmillan.

Spearman, C. & Jones, L. W. (1959). *Human ability: A continuation of "The Abilities of Man".* London: Macmillan.

Sternberg, R. J. (1990). Wisdom and its relations to intelligence and creativity. In R. J. Sternberg (Ed.), *Wisdom: Its nature, origins, and development* (pp. 142-159). New York: Cambridge University Press.

Thorndike, R. L., Lay, W., & Dean, P. R. (1909). The relation of accuracy in sensory discrimination to general intelligence. *American Journal of Psychology*, 20, 364-369. Retrieved from http://www.jstor.org/stable/1413366.

Thurstone, L. L. (1938). *Primary mental abilities.* Chicago: University of Chicago Press.

Thurstone, L. L. (1947). *Multiple factor analysis: A development and expansion of the vectors of the mind.* Chicago: University of Chicago Press.

Vernhaeghen, P., & Salthouse, T. A. (1997). Meta-analyses of age-cognition relations in adulthood: Estimates of linear and non-linear age effects and structural models. *Psychological Bulletin, 122,* 231-249.

Vernon, P. E. (1950). *The structure of human abilities*. London: Methuen.

Wasserman, J. D. (2012). A history of intelligence assessment: The unfinished tapestry. In D. P. Flanagan & P. L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues. (*3rd Ed., pp. 3-54). New York: Guilford Press.

Wechsler, D. (1949). *Wechsler intelligence scale for children*. New York: The Psychological Corporation.

Wechsler, D. (2014). *Wechsler Intelligence Scale for Children - Fifth Edition.* Bloomington, MN: Pearson.

Woodcock, R. W. (1990). Theoretical foundations of the WJ-R measures of cognitive ability. *Journal of Psychoeducational Assessment, 8,* 231-258.

Woodcock, R. W., & Johnson, M.B. (1989). *Woodcock-Johnson Psycho-Educational Battery—Revised*. Allen, TX: DLM Teaching Resources.

Table 1

Comparison of Functional (F-CHC) and Scientific CHC Nomenclatures

Functional CHC Nomenclature		Scientific CHC Nomenclature	
Broad Abilities	Narrow Abilities	Broad Abilities	Narrow Abilities
Acquired Knowledge		Acquired Knowledge	
(*Gc*) Comprehension-Knowledge	(*Gc*-VA) Verbal Ability	(*Gc*) Crystallized Intelligence	LD: Language Development LS: Listening Ability VL: Lexical Knowledge
	(*Gc*-K) Factual Knowledge		K0: General Verbal Information
(*Grw*-R) Broad Reading	(*Grw*-RS) Reading Skills	*Grw*: Reading and Writing	RD: Reading Decoding
	(Grw-RC) Reading Comprehension		RC: Reading Comprehension RS: Reading Speed
(*Grw*-W) Broad Writing	(*Grw*-WS) Writing Skills		SG: Spelling Ability EU: English Usage
	(*Grw*-WC) Writing Composition		WA: Writing Ability WS: Writing Speed
(*Gq*) Broad Mathematics	(*Gq*-C) Calculation	*Gq*: Quantitative Knowledge	A3: Mathematical Achievement
	(*Gq*-Ap) Applied Math		KM: Mathematical Knowledge
(*Gp*) Psychomotor Abilities	(*Gp*) Handwriting		
Thinking Abilities		Thinking Abilities	
(*Gv*) Visual-Spatial Processing	(*Gv*-PP) Pictorial Processing	*Gv*: Visual Processing	CS: Closure Speed
	(*Gv*-SP) Spatial Processing		VZ: Visualization SR: Spatial Relations SS: Spatial Scanning

Functional CHC Nomenclature		Scientific CHC Nomenclature	
Broad Abilities	Narrow Abilities	Broad Abilities	Narrow Abilities
(*Ga*) Auditory Processing	(*Ga*-SD) Sound Discrimination	*Ga:* Auditory Processing	US: Speech Sound Discrimination UR: Resistance to Auditory Stimulus Distortion
	(*Ga*-Ph) Phonetics		U3: Sound Discrimination PC: Phonetic Coding
(*Glm*) Learning-Memory	(*Glm*-IR) Immediate Recall	*Gl*: Learning Efficiency	MA: Associative Memory MM: Meaningful Memory M6: Free-Recall Memory MV: Visual Memory
	(*Glm*-MR) Memory Retrieval	*Gr*: Retrieval Fluency	FI: Ideational Fluency FA: Associational Fluency FE: Expressional Fluency SP: (Sensitivity to Problems/ Alternative Solution Fluency) FO: Originality/ Creativity NA: Naming Facility FW: Word Fluency LA: Speed of Lexical Access FF: Figural Fluency FX: Figural Flexibility

Functional CHC Nomenclature		Scientific CHC Nomenclature	
Broad Abilities	Narrow Abilities	Broad Abilities	Narrow Abilities
(*Gr*) Reasoning	(*Gr*-CR) Contextual Reasoning	*Gf*: Fluid Reasoning	RQ: Quantitative or Numerical Reasoning
	(*Gr*-ID) Inductive/Deductive Reasoning		I: Induction RG: General Sequential Reasoning
Cognitive Efficiency		Cognitive Efficiency	
(*Gcm*) Conscious Memory	(*Gcm*-MS) Memory Span	*Gsm*: Short-Term Memory	MS: Memory Span
	(*Gcm*-WM) Working Memory		MW: Working Memory WM: Working Memory Capacity AC: Attentional Control
(*Gs*) Cognitive Processing Speed	(*Gs*-PS) Perceptual Speed	*Gs*: Processing Speed	P: Perceptual Speed AC: Attention and Concentration
	(*Gs*-TS) Thinking Speed		R9: Rate of Test Taking N: Number Facility