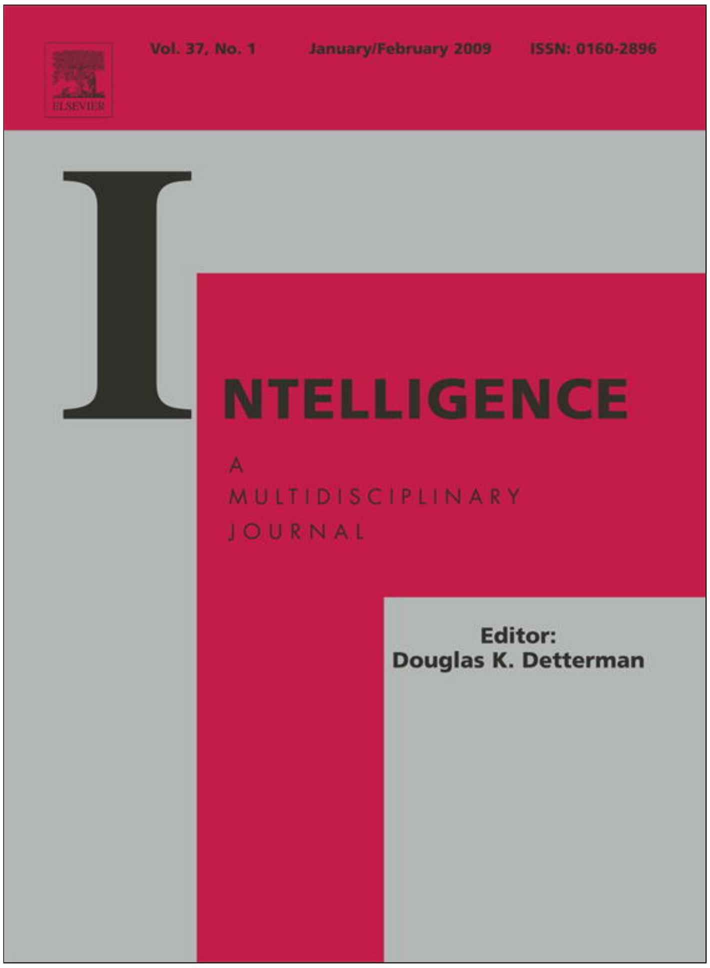
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Editorial

CHC theory and the human cognitive abilities project: Standing on the shoulders of the giants of psychometric intelligence research

Kevin S. McGrew *

Woodcock-Muñoz Foundation, University of Minnesota, United States

A R T I C L E I N F O

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A B S T R A C T

During the past decade the Cattell–Horn Gf–Gc and Carroll Three-Stratum models have emerged as the consensus psychometric-based models for understanding the structure of human intelligence. Although the two models differ in a number of ways, the strong correspondence between the two models has resulted in the increased use of a broad umbrella term for a synthesis of the two models (Cattell–Horn–Carroll theory of cognitive abilities—CHC theory).

The purpose of this editorial is three-fold. First, I will describe the CHC framework and recommend that intelligence researchers begin using the CHC taxonomy as a common nomenclature for describing research findings and a theoretical framework from which to test hypotheses regarding various aspects of human cognitive abilities. Second, I argue that the emergence of the CHC framework should not be viewed as the capstone to the psychometric era of factor analytic research. Rather, I recommend the CHC framework serve as the stepping stone to reinvigorate the investigation of the structure of human intelligence.

Finally, the Woodcock-Muñoz Foundation Human Cognitive Abilities (HCA) project, which is an evolving, free, on-line electronic archive of the majority of datasets analyzed in Carroll's (1993) seminal treatise on factor analysis of human cognitive abilities, is introduced and described. Intelligence scholars are urged to access the Carroll HCA datasets to test and evaluate structural models of human intelligence with contemporary methods (confirmatory factor analysis). In addition, suggestions are offered for linking the analysis of contemporary data sets with the seminal work of Carroll. The emergence of a consensus CHC taxonomy and access to the original datasets analyzed by Carroll provides an unprecedented opportunity to extend and refine our understanding of human intelligence.

As far as I know, there is only one universal proven law of human behavior—the law of individual differences. Since the beginning of time humans have searched for means to describe, order, measure and classify our perceptions and experiences, including observed similarities and differences between and among individuals and groups. Classification has arguably become one of the most central conceptual exercises related to scientific work (Dunn & Everitt, 1982). Taxonomy, the specialized science and practice of classification of empirical observations, guides the search for information and truth in most all scientific endeavors (Bailey, 1994).

1. Searching for the Holy Grail of cognitive abilities

"One of the most successful undertakings attributed to modern psychology is the measurement of mental abilities. Though rarely appreciated outside academe, the breakthrough in objectively gauging the nature and range of mental abilities is a pivotal development in the behavioral sciences" (Lamb, 1994, p. 386). The birth of psychometric taxonomic efforts is typically associated with Spearman (1904). Most post-Spearman treatments of the extant psychometric intelligence research cover the major researchers and theories (e.g., Thurstone's Primary Mental Abilities; Cattell and Horn's Gf–Gc theory; Vernon's hierarchical theory), describe group efforts to establish Well Replicated Common Factors, also known as WERCOF abilities (Eckstrom,

* 1313 Pondview Lane E, St. Joseph, MN 56374, United States. Tel.: +1 320 260 1309.
E-mail address: iap@earthlink.net.

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French, & Harman, 1979; French, 1951; French, Eckstrom, & Price, 1963; Guilford, 1967; Hakstian & Cattell, 1974; Horn, 1972), or provide broad conceptual organizing schemes (e.g., the American and British traditions).

During the formative years of factor analytic intelligence research a comprehensive taxonomy of human cognitive abilities proved evasive. The absence of a consensus taxonomy of cognitive abilities was not due to a lack of interest or effort. While visiting Dr. John "Jack" Carroll in May of 2003 (one month prior to his death), he provided me access to the personal collection of disks, cabinets, books, computers, files, and other materials he had taken with him when he retired to Alaska. One afternoon, while randomly selecting copies of letters from his meticulously organized and massive collection of professional correspondence, I happened upon a copy of a January 31, 1957 letter from Raymond B. Cattell to Dr. Roger W. Russell, Executive Secretary of the American Psychological Association (APA). A handwritten personal note, from Cattell to Carroll, was at the top of the letter. The note read: "Dear J. Carroll. Many thanks for your letters. This is to keep you in touch with steps taken. I hope you will feel that this amount of funds will suffice to get us started, at any rate." Below is an excerpt from the Cattell–Rogers letter that provides the proper context for the Cattell-to-Carroll note.

> Dear Roger: Thank you for your care in evaluating the principal issues in regard to my proposed Committee for the Evaluation and Indexing of Psychological Factors. In reply to the question raised in first and third of the informal comments which you have passed to me, I feel very strongly that such a committee should be an APA committee if it is to be of any use at all. The function we have in mind is something analogous to the fixing of the standard meter, by physicists, or of the choice of hydrogen in determining atomic weights by chemists. It is not a question of great research insight, which must be left to the isolated individual and cannot be supplied by an APA committee. It is rather a question of fixing an authorative stamp, which all can recognize, upon a system of scientific currency. It is possible that in half a century's time, such a committee might stand on its own feet, as perhaps the Bureau of Standards in Washington, or the National Physical Laboratory at Teddington in England, now stands apart from the Physical Societies concerned. . . . As psychology progresses more beyond the stage of "talking about things which everybody knows in language which nobody understands", I suspect there will be a need for more work by APA in fixing scientific and quantitative standards in a variety of fields.

It is clear that a group of intelligence scholars, during the formative and adolescent periods of psychometric structural research, were keenly aware of the need to organize the growing body of human cognitive ability factor analysis research. The lack of an organized taxonomy was clearly not due to a lack of motivation and interest.

According to Carroll (1993), the first attempts to survey and inventory the correlation and factor analysis research occurred in 1940 (Wolfe, 1940) and 1951 (French, 1951). The period from 1952 to approximately 1976 was particularly productive as Educational Testing Service (ETS) sponsored a series of activities and conferences to develop a standard kit of reference tests for factor analysis studies (Carroll, 1993), much in line with the spirit and intent of Cattell's (1957) APA letter. This organized set of activities focused on establishing a set of Well Replicated Common Factors (Horn, 1989). The capstone monograph-length publication *Review of Cognitive Factors* was authored by Ekstrom, French and Harman (1979).

2. A working taxonomy of cognitive abilities emerges

Aside from a series of brief summaries by John Horn (Horn, 1976, 1978, 1985, 1988; see Carroll, 1993), it wasn't until the publication of Carroll's (1993) seminal treatise *Human Cognitive Abilities: A Survey of Factor-Analytic Studies* that a comprehensive systematic organization of the extant research on the structure of human cognitive abilities emerged. Carroll reported the results of his systematic exploratory factor analysis (EFA) of over 460 carefully selected human cognitive ability datasets, many of which were classic datasets reported during the prior 50 to 60 years. Carroll's work built on the research of numerous giants in the field of intelligence (e.g., Raymond Cattell, John Horn, L. L. Thurstone, Robert Thorndike). As I have previously described (McGrew, 2005), I believe Carroll's (1993) publication represents to the field of applied psychometrics a work similar in stature to other *principia* publications in other scientific fields (e.g., Newton's three volume, *The Mathematical Principles of Natural Philosophy*, or *Principia* as it became known and Whitehead & Russell's, *Principia Mathematica*).

I am not alone in the elevation of Carroll's work to such esteemed company. Burns (1994) stated that Carroll's book "is simply the finest work of research and scholarship I have read and is destined to be the classic study and reference work on human abilities for decades to come" (p. 35). Horn (1998) described Carroll's (1993) work as a tour de force summary and integration that is the "definitive foundation for current theory" (p. 58). Horn compared Carroll's summary to Mendelyev's presentation of chemistry's periodic table of elements. 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.5).

The major strength of Carroll's meta-factor analysis was that, for the first time ever, an empirically-based taxonomy of human cognitive ability elements was presented in a single organized framework. The raw material reviewed and analyzed by Carroll drew on decades of research by a diverse array of dedicated researchers. The research of Cattell and Horn played a particularly prominent role in Carroll's eventual three-tier (stratum) hierarchical model. According to Carroll (1993), the Cattell–Horn Gf–Gc model "appears to offer the most well-founded and reasonable approach to an acceptable theory of the structure of cognitive abilities" (p. 62). There are remarkable similarities between the Carroll Three-Stratum and Cattell–Horn Gf–Gc models, so much so that a single umbrella term (viz., the *Cattell–Horn–Carroll [CHC]* theory of intelligence) was proposed to reflect the broad stroke communality of these two most prominent theoretical models (Daniel, 1997, 2000; McGrew, 1997, 2005; Snow, 1998; Sternberg & Kaufman, 1998).

3. The CHC taxonomy: brief overview

The recognition and influence of the CHC taxonomic umbrella has increased steadily during the past 10 years, particularly in professional fields engaged in the use of applied individual batteries of intelligence (e.g., school psychology).[1] The adoption of the CHC umbrella term has been much slower in theoretical fields, such as research published in the journal *Intelligence*,[2] a situation that appears to be changing the past few years. It is hoped that this editorial will convince ISIR members and readers of *Intelligence* of the value of considering CHC theory as a common nomenclature for describing research findings and a theoretical framework from which to test hypotheses regarding various aspects of human cognitive abilities (including the framework itself).

Fig. 1 includes schematic representations and comparisons of the broad strokes of Carroll's Three-Stratum (1993, 1997, 2005) and Cattell–Horn's Extended Gf–Gc (Horn & Blankson, 2005; Horn & Noll, 1997) models.[3] The primary differences between the two models are (a) the presence (Carroll) or absence (Cattell–Horn) of a general intelligence (g) factor at Stratum III, (b) the inclusion (Cattell–Horn) or exclusion (Carroll) of a quantitative knowledge domain (Gq) at Stratum II, (c) the inclusion of reading and writing abilities under Gc (Carroll) or as a separate Stratum II ability (Cattell–Horn), and (d) the separation of short-term memory (Gsm) and longer-term storage and retrieval (SAR, Glm) in the Cattell–Horn model and the inclusion of both classes of memory under a single Gy factor in the Carroll model.

The inclusion of "tentatively identified Stratum II (broad) ability domains" in the CHC model in Fig. 1 reflects the recognition that "for any taxonomic model of human cognitive abilities to be complete, all sensory modalities must be encompassed within its framework" (Danthiir, Roberts, Pallier & Stankov, 2001). Currently most treatments of CHC theory (and the foundational Carroll and Cattell–Horn models) typically recognize up to nine broad abilities (Gf, Gc, Gv, Ga, Gsm, Glr, Gs, Gq, Grw). However, a significant gap exists in the CHC taxonomy regarding the human sensory domains of tactile, kinesthetic, and olfactory abilities (Danthiir et al., 2001; Stankov, 2000). A review of the factor analytic research (McGrew, 2005) during the past decade (1993–2003) argues for the inclusion of at least six potential additional broad ability domains (Gkn, Gh, Gk, Go, Gp, Gps) to the CHC taxonomy. Table 1 includes a comparison of the CHC, Carroll, and Cattell–Horn broad ability labels and currently accepted definitions for the CHC Stratum II broad ability domains (McGrew, 2005).

3.1. CHC taxonomy caveats

It is important that intelligence scholars and users of intelligence batteries resist being blinded by the landmark importance of the current CHC taxonomy. It is tempting to fall prey to the premature hardening of the ability categories. As noted by one of the primary architects of CHC theory (John Horn), "the extended theory of fluid and crystallized (Gf and Gc) cognitive abilities is wrong, of course, even though it may be the best account we currently have of the organization and development of abilities thought to be indicative of human intelligence. All scientific theory is wrong. It is the job of science to improve theory" (Horn & Blankson, 2005, p. 41). Carroll (2005) sounded a similar note when he concluded that "much work remains to be done in the factor analytic study of cognitive abilities. The map of abilities provided by the three-stratum theory undoubtedly has errors of commission and omission, with gaps to be filled in by further research" (p. 75). So, for example, Carroll (1993) suggested that there were likely unexplored intermediate abilities between his second and third strata. Although the types of research (e.g., heritability, neurocognitive, developmental, outcome-criterion, structural research) necessary to continue the validation, refinement and extension of the CHC taxonomy are many, the purpose of this article is focused on one—structural or factor analytic evidence for the CHC taxonomy.

In addition, it is readily acknowledged that the integration of Carroll and Cattell–Horn's models under a single CHC umbrella term is not based on a series of comprehensive empirical CFA comparison studies. I first proposed a *synthesized* Carroll and Cattell–Horn Gf–Gc framework in a 1997 book chapter for a pragmatic reason—the need for a single broad and narrow ability taxonomy by which to initially classify the narrow abilities measured by the tests in the major individually administered intelligence batteries. In the process, I used the standardization data from the WJ-R battery (McGrew, Werder & Woodcock, 1991) to evaluate a number of alternative Carroll and Cattell–Horn models.[4] These analyses suggested that (a) Gq is a distinct broad ability and is not subsumed by Gf, (b) Grw should

[1] Informal evidence can be found in the recent publication of four individually administered major intelligence batteries based primarily on the CHC theory of cognitive abilities (viz., Differential Ability Scales—II, Elliott, 2007; Kaufman Assessment Battery for Children II, Kaufman & Kaufman, 2004; Stanford–Binet IV, Roid, 2003; Woodcock–Johnson Battery III, Woodcock, McGrew & Mather, 2001) and publications devoted to CHC-grounded cross-battery assessment and interpretation procedures (Flanagan, Ortiz, & Alfonso, 2007; McGrew & Flanagan, 1998;) as a means by which to interpret non-CHC batteries or batteries with weak CHC ability representation (e.g., Wechsler batteries) as per the CHC framework. An informal *PsychINFO* search found 29 journal publications since 2000 that included either "CHC" or "Cattell–Horn–Carroll" in the title, abstract or text. Twenty-two (75.8%) of the articles were in one of the major school psychology related journals (*Journal of Psychoeducational Assessment, Journal of School Psychology, School Psychology Quarterly, Psychology in the Schools, Canadian Journal of School Psychology*). Three additional articles were in journal publications in fields strongly associated with school psychology such as developmental disabilities (*American Journal on Mental Deficiency*), reading and reading disabilities (*Reading and Writing*), and ADHD (*Journal of Attention Disorders*). Of interest was the finding that a separate search using the phrase "Gf–Gc" identified the same 29 journal citations. I interpret this 1-to-1 CHC/Gf–Gc search correspondence as an indication that, in the primary applied professions that use intelligence tests for school and learning-related concerns, there is recognition of CHC theory as an integration or amalgam of Carroll's Three-Stratum and the Cattell–Horn Gf–Gc theories.

[2] An informal search of *Intelligence*, via the Elsevier on-line search function, found over 70 articles (published between 2000 and 2008) with the keyword "Gf–Gc" and only 7 with "CHC" or "Cattell–Horn–Carroll." Of interest was the observation that 6 of the 7 CHC/Cattell-Horn-Carroll identified articles in *Intelligence* were published between 2006 and 2008 (with 3 being *in press* articles at the time of this writing). It would appear that the CHC nomenclature is just starting to be recognized in *Intelligence*.

[3] See McGrew (1997, 2005) for a detailed treatment of the similarities and differences between the Carroll and Cattell–Horn models as well as a historical summary of how they became integrated under the CHC umbrella.

[4] A summary of the final CFA model is included in McGrew (1997).

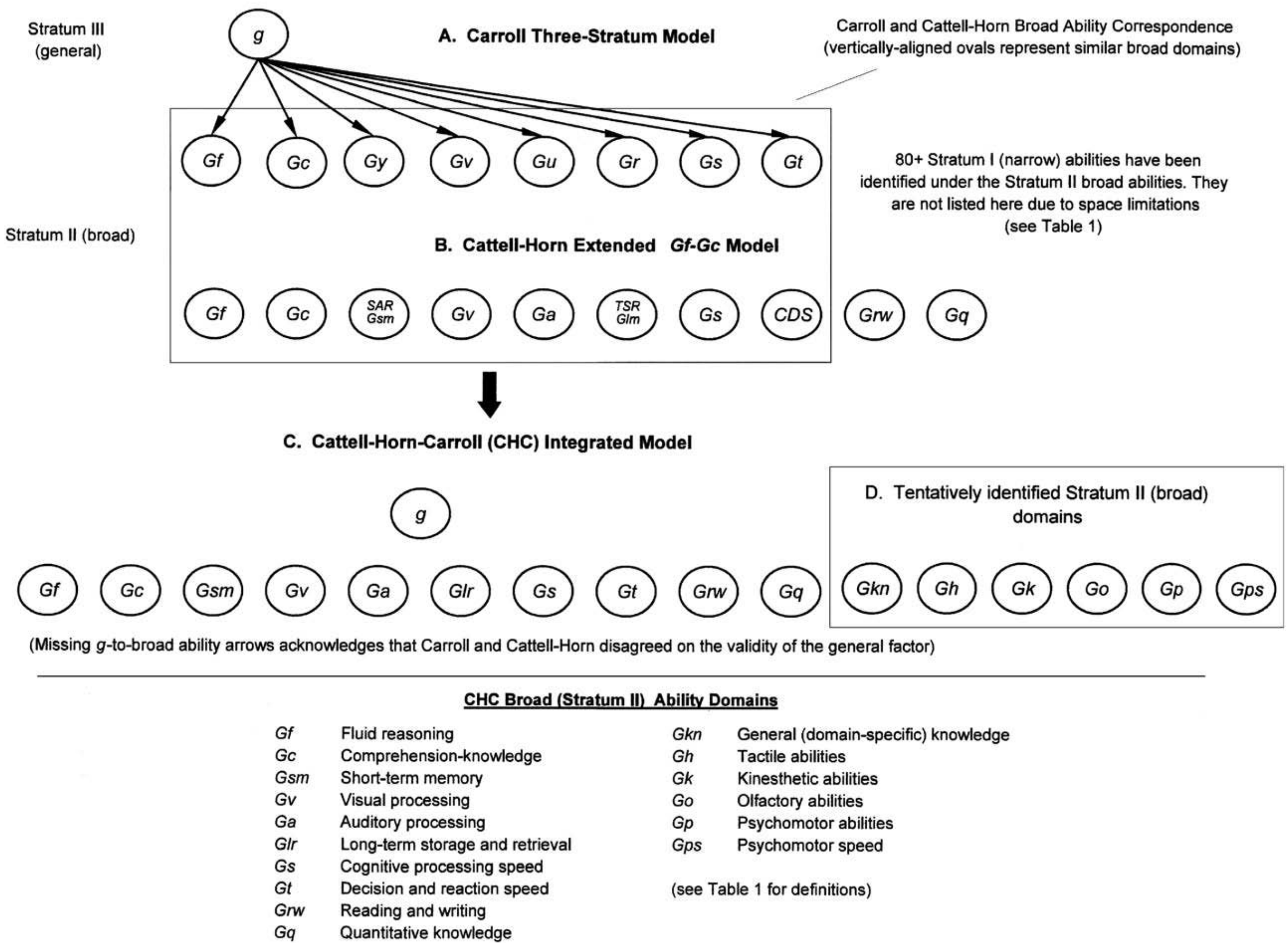

Fig. 1. Schematic representation and comparisons of Carroll's Three-Stratum, Cattell–Horn's Extended Gf–Gc, and the integrated Cattell–Horn–Carroll models of human cognitive abilities.

be a separate broad ability distinct from Gc, and (c) short-term memory (Gsm) and longer-term storage and retrieval (Glr) abilities should be separate broad abilities. To date I know of no single study with a sufficient breadth of CHC ability test indicators that has provided evidence that the current CHC model is the most accurate and valid integration or amalgam of the Carroll and Cattell–Horn models. I look forward to seeing such research. It is hoped that serious scholars of intelligence accept the CHC framework for what it is—a well-reasoned (and partially empirically tested) psychometric taxonomic framework (grounded in the extant factor analytic research that produced the Carroll and Cattell–Horn models) that can improve research vis-à-vis the use of a common nomenclature.

As noted previously there are indicators that the CHC taxonomy is serving a strong theory-to-practice-gap bridging function in the field of applied intelligence test development and interpretation. Most important have been a series of CHC-organized studies that have demonstrated that some CHC broad and narrow cognitive abilities are important in explaining school achievement above and beyond the effect of *g*, and that revealed that *g*'s influence may be best understood as an indirect effect mediated by broad and narrow abilities (Bensen, 2008; Flanagan, 2000; Floyd, Keith, Taub, & McGrew, 2007; Keith, 1999; McGrew, Flanagan, Keith, & Vanderwood, 1997; Taub, Floyd, Keith, & McGrew, 2008; Vanderwood, McGrew, Flanagan, & Keith, 2002). Recent and forthcoming *Intelligence* articles suggest that intelligence scholars are also beginning to see the benefits of the CHC integrative umbrella for organizing their research. Recent examples from *Intelligence* include studies of the *g*-saturation of broad abilities (Arendasy, Hergovich & Sommer, in press), gender differences in CHC broad abilities (Camarata & Woodcock, 2006; Keith, Reynolds, Patel & Ridley, in press), the importance of broad abilities–above and beyond the influence of *g*–in the explanation of domain-specific knowledge (Reeve, 2004), the relations between select broad cognitive abilities, personality and interests and future current events knowledge (Hambrick, Pink, Meinz, Pettibone & Oswald, 2008), and a test of Cattell's Investment Theory (Kvist & Gustafsson, in press). Yet another example of the recognition of the value of the CHC framework in intelligence research has been McPherson and Burns (2005, 2007) systematic CHC-conceptualized program of research to develop and validate computer game-like tests of Gs (McPherson & Burns, 2005).

Interestingly, a number of recent *Intelligence* publications were based on analysis of the KABC II or WJ III batteries, batteries explicitly designed to measure the CHC model, yet no mention is made in the articles of the CHC framework. Select examples include Reynolds and Keith's (2007) SLODR analysis

Table 1
CHC broad ability domain terms, corresponding Cattell–Horn and Carroll broad ability terms, and broad ability definitions and identified narrow abilities

CHC broad abilities [a]	Cattell–Horn broad abilities [b]	Carroll broad abilities [c]	CHC broad ability definitions and identified narrow abilities [d]
Fluid reasoning (Gf)	Fluid reasoning (Gf)	Fluid intelligence (Gf)	The use of deliberate and controlled mental operations to solve novel problems that cannot be performed automatically. Mental operations often include drawing inferences, concept formation, classification, generating and testing hypothesis, identifying relations, comprehending implications, problem solving, extrapolating, and transforming information. Inductive and deductive reasoning are generally considered the hallmark indicators of Gf. Gf has been linked to cognitive complexity which can be defined as a greater use of a wide and diverse array of elementary cognitive processes during performance. • General sequential (deductive) reasoning (RG); Induction (I); Quantitative reasoning (RQ), Piagetian reasoning (RP), Speed of reasoning (RE)
Comprehension-knowledge (Gc)	Acculturation knowledge (Gc)	Crystallized intelligence (Gc)	The knowledge of the culture that is incorporated by individuals through a process of acculturation. Gc is typically described as a person's breadth and depth of acquired knowledge of the language, information and concepts of a specific culture, and/or the application of this knowledge. Gc is primarily a store of verbal or language-based declarative (knowing what) and procedural (knowing how) knowledge acquired through the investment of other abilities during formal and informal educational and general life experiences. • Language development (LD), Lexical knowledge (VL), Listening ability (LS), General (verbal) information (K0), Information about culture (K2), Communication ability (CM), Oral production and fluency (OP), Grammatical sensitivity (MY), Foreign language proficiency (KL), Foreign language aptitude (LA)
Short-term memory (Gsm)	Short-term apprehension and retrieval (SAR, Gsm)	General memory and learning (Gy)	The ability to apprehend and maintain awareness of a limited number 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), Working memory (MW) [e]
Visual processing (Gv)	Visual processing (Gv)	Broad visual perception (Gv)	The ability to generate, store, retrieve, and transform visual images and sensations. Gv abilities are typically measured by tasks (figural or geometric stimuli) that require the perception and transformation of visual shapes, forms, or images and/or tasks that require maintaining spatial orientation with regard to objects that may change or move through space. • Visualization (Vz), Spatial relations (SR), Closure speed (CS), Flexibility of closure (CF), Visual memory (MV), Spatial scanning (SS), Serial perceptual integration (PI), Length estimation (LE), Perceptual illusions (IL), Perceptual alternations (PN), Imagery (IM)
Auditory processing (Ga)	Auditory processing (Ga)	Broad auditory perception (Gu)	Abilities that depend on sound as input and on the functioning of our hearing apparatus. A key characteristic is the extent an individual can cognitively control (i.e., handle the competition between signal and noise) the perception of auditory information. The Ga domain circumscribes a wide range of abilities involved in the interpretation and organization of sounds, such as discriminating patterns in sounds and musical structure (often under background noise and/or distorting conditions) and the ability to analyze, manipulate, comprehend and synthesize sound elements, groups of sounds, or sound patterns. • Phonetic coding (PC), Speech sound discrimination (US), Resistance to auditory stimulus distortion (UR), Memory for sound patterns (UM), General sound discrimination (U3), Temporal tracking (UK), Musical discrimination and judgment (U1 U9), Maintaining and judging rhythm (R8), Sound-intensity/duration discrimination (U6), Sound-frequency discrimination (U5), Hearing and speech threshold factors (UA UT UU), Absolute pitch (UP), Sound localization (UL)
Long-term storage and retrieval (Glr)	Long-term storage and retrieval (TSR, Glm)	Broad retrieval ability (Gr)	The ability to store and consolidate new information in long-term memory and later fluently retrieve the stored information (e.g., concepts, ideas, items, names) through association. Memory consolidation and retrieval can be

(continued on next page)

Table 1 (*continued*)

CHC broad abilities [a]	Cattell–Horn broad abilities [b]	Carroll broad abilities [c]	CHC broad ability definitions and identified narrow abilities [d]
			measured in terms of information stored for minutes, hours, weeks, or longer. Some Glr narrow abilities have been prominent in creativity research (e.g., production, ideational fluency, or associative fluency). • Associative memory (MA), Meaningful memory (MM), Free-recall memory (M6), Ideational fluency (FI), Associational fluency (FA), Expressional fluency (FE), Naming facility (N), Word fluency (FW), Figural fluency (FF), Figural flexibility (FX), Sensitivity to problems (SP), Originality/creativity (FO), Learning abilities (L1)
Processing speed (Gs) [f]	Cognitive processing speed (Gs)	Broad cognitive speediness (Gs)	The ability to automatically and fluently perform relatively easy or over-learned elementary cognitive tasks, especially when high mental efficiency (i.e., attention and focused concentration) is required. • Perceptual speed (P), Rate-of-test-taking (R9), Number facility (N), Speed of reasoning (RE), Reading speed (RS), Writing speed (WS)
Reaction and decision Speed (Gt) [f]	Correct decision speed (CDS)	Processing speed (RT decision speed)	The ability to make elementary decisions and/or responses (simple reaction time) or one of several elementary decisions and/or responses (complex reaction time) at the onset of simple stimuli. Typically measured by chronometric measures of reaction and inspection time. • Simple reaction time (R1), Choice reaction time (R2), Semantic processing speed (R4), Mental comparison speed (R7), Inspection time (IT)
Reading and writing (Grw)	Reading and writing (Grw) [g]	(Carroll included reading and writing narrow abilities under Gc)	The breadth and depth of a person's acquired store of declarative and procedural reading and writing skills and knowledge. Grw includes both basic skills (e.g., reading and spelling of single words) and the ability to read and write complex connected discourse (e.g., reading comprehension and the ability to write a story). • Reading decoding (RD), Reading comprehension (RC), Verbal (printed) language comprehension (V), Cloze ability (CZ), Spelling ability (SG), Writing ability (WA), English usage knowledge (EU), Reading speed (RS), Writing speed (WS)
Quantitative knowledge (Gq)	Quantitative knowledge (Gq)	(Carroll included math achievement factors in a chapter on "Abilities in the domain of knowledge and achievement.")	The breadth and depth of a persons acquired store of declarative and procedural quantitative or numerical knowledge. Gq is largely acquired through the investment of other abilities primarily during formal educational experiences. Gq represents an individual's store of acquired mathematical knowledge, not reasoning with this knowledge. • Mathematical knowledge (KM), Mathematics achievement (A3)
General (domain-specific) knowledge (Gkn)		(Carroll included specialized knowledge and achievement factors in a chapter on "Abilities in the domain of knowledge and achievement.")	The breadth, depth and mastery of a person's acquired knowledge in specialized (demarcated) subject matter or discipline domains that typically do not represent the general universal experiences of individuals in a culture (Gc). Gkn reflects deep specialized knowledge domains developed through intensive systematic practice and training (over an extended period of time) and the maintenance of the knowledge base through regular practice and motivated effort (a.k.a., expertise). • Knowledge of English as a second language (KE), Knowledge of signing (KF), Skill in lip-reading (LP), Geography achievement (A5), General science information (K1), Mechanical knowledge (MK), Knowledge of behavioral content (BC)
Tactile abilities (Gh)		(Carroll included tactile sensitivity factors in a chapter on "Miscellaneous domains of ability and personal characteristics.")	Abilities involved in the perception and judging of sensations that are received through tactile (touch) sensory receptors. Includes abilities involved in the judgment of thermal stimulation, spatial stimulation, or patterns imposed on the skin. The cognitive and perceptual aspects of this domain have not yet been widely investigated. • Tactile sensitivity (TS)
Kinesthetic abilities (Gk)		(Carroll included kinesthetic sensitivity factors in a chapter on "Miscellaneous domains of ability and personal characteristics.")	Abilities that depend on sensory receptors that detect bodily position, weight, or movement of the muscles, tendons, and joints. Abilities involved in the process of controlling and coordinating body movements, including walking, talking, facial expressions, gestures and posture. The cognitive and perceptual aspects of this domain have not yet been widely investigated. • Kinesthetic sensitivity (KS)

Table 1 (*continued*)

CHC broad abilities [a]	Cattell–Horn broad abilities [b]	Carroll broad abilities [c]	CHC broad ability definitions and identified narrow abilities [d]
Olfactory abilities (Go)		(Carroll included olfactory sensitivity factors in a chapter on "Miscellaneous domains of ability and personal characteristics.")	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. • Olfactory memory (OM), Olfactory sensitivity (OS)
Psychomotor abilities (Gp)		(Carroll included psychomotor factors in a "Psychomotor abilities" chapter.)	The ability to perform physical body motor movements (movement of fingers, hands, legs, etc) with precision, coordination, or strength. Movement or motor behaviors are typically the result of mental activity. • Static strength (P3), Multi-limb coordination (P6), Finger dexterity (P2), Manual dexterity (P1), Arm-hand steadiness (P7), Control precision (P8), Aiming (A1), Gross body equilibrium (P4)
Psychomotor speed (Gps) [f]		(Carroll included psychomotor speed factors in a "Psychomotor abilities" chapter.)	The ability to rapidly and fluently perform physical body motor movements (movement of fingers, hands, legs, etc.) largely independent of cognitive control. • Speed of limb movement (R3), Writing speed (WS), Speed of articulation (PT), Movement time (MT)

[a] The first published use of the CHC broad ability terms, although then couched in terms of Cattell–Horn Gf–Gc theory, was the publication of the Woodcock–Johnson Psycho-Educational Battery-Revised (WJ-R: Woodcock & Johnson, 1989; McGrew et al., 1991). As discussed elsewhere (see McGrew, 2005), Horn and Carroll were theoretical consultants on the WJ-R and the subsequent WJ III. Given the applied nature of the WJ-R battery, the WJ-R authors modified some of the broad ability terms then in use in the Cattell–Horn Gf–Gc theory literature.

[b] Stratum II broad ability terms and code abbreviations (e.g., Gf) taken from one of Horn's last Gf–Gc theory summary publications (Horn & Blankson, 2005). Readers of Horn's writings typically notice that he frequently modified or changed the terms and labels for broad abilities, often within the same publication. For example, in Horn and Blankson (2005), the ability of "fluency of retrieval from long-term storage (TSR)" (p.43) is defined early in the chapter and subsequently is referenced as "tertiary storage and retrieval" (p.47) and also "abilities of long-term storage and retrieval" (p.45).

[c] Stratum II broad ability terms and code abbreviations (e.g., Gf) taken from Carroll (1993).

[d] Space does not allow for inclusion of the definitions for the narrow abilities. Narrow ability definition summaries can be found in McGrew (2005), Flanagan et al. (2007), and Flanagan, Ortiz , Alfonso and Mascolo (2006). The definitions in these various sources are all based on an initial set of narrow ability definitions provided by McGrew (1997). In preparation of my 1997 chapter, I extracted definitions from Carroll (1993). A working set of definitions was sent to Dr. Carroll and he and I exchanged iterated revisions until he was comfortable with the final definitions. These definitions are also available on-line at: http://www.iapsych.com/chcdef.htm.

[e] Research suggests that MW is not of the same nature as the other narrow factor-based trait-like individual difference constructs included in this table. MW is a theoretically developed construct (proposed to explain memory findings from experimental and information processing research) and not a label for an individual-differences type factor. MW is retained in the current CHC taxonomy table as a reminder of the importance of this construct in understanding new learning and performance of complex cognitive tasks (see McGrew, 2005).

[f] In a recent review of the factor analytic research, McGrew (2005) presented a hypothesized speed hierarchy based on an integration of Carroll (1993) identified speed abilities and recent research (Ackerman, Beier & Boyle, 2002; O'Connor & Burns, 2003; McGrew & Woodcock, 2001; Roberts and Stankov, 1999; Stankov, 2000; Stankov & Roberts, 1997). The hypothesized speed hierarchy included a stratum III general speed (g-speed) factor, three Stratum II broad abilities (Gs—Broad Cognitive Speed; Gt—Broad Decision Speed; Gps—Broad Psychomotor Speed), the possibility of 15 Stratum I narrow abilities, and four intermediate level (between Stratum I and II) abilities of Perceptual Speed, Rate-of-test Taking, Reaction Time and Movement Time).

[g] Horn discussed a precursor of Grw when he described a language use factor in 1988. However, it was primarily the work of Woodcock (McGrew et al., 1991; Woodcock, 1994) that resulted in the description and labeling of this domain as broad reading and writing (Grw).

of the KABC II, Luo, Thompson and Detterman's (2006) evaluation of the criterion validity of measures of basic cognitive processes (WJ III), and Murray's (2007) analysis of changes in black–white IQ differences across all three editions of the WJ III battery. All three publications frequently reference the KABC II and WJ III manuals, the seminal and foundational works of the Carroll and Cattell–Horn models, and refer to the underlying theory as Gf–Gc theory. From this small sampling of select *Intelligence* publications (that either use or do not use the language of CHC theory) it appears that the recognition of the CHC taxonomy in *Intelligence* publications is inconsistent.

4. Refining and extending the CHC taxonomy: back to the future

It is my belief that the emergence of the CHC taxonomy should not be viewed as the end of psychometric research on the structure of human abilities, but instead, it should reinvigorate the field to refine the CHC taxonomy via internal external extension research (studies of the primarily recognized broad and narrow CHC abilities; e.g., Gf, Glr) and external (studies of tentatively identified broad ability domains; e.g., Gkn, Gh) extension research (Stankov, 2000). I recommend a renewed focus on the examination of the past and emerging structural evidence for the CHC taxonomy vis-à-vis two complimentary, strategies.

First, we should undertake a retrospective reanalysis of the datasets analyzed by Carroll with contemporary statistical methods (e.g., confirmatory factor analysis; CFA). Carroll (1993) alluded to this need when he suggested that "our findings could be confirmed by applying confirmatory techniques (e.g., LISREL or EQS analysis) to the datasets…the hierarchical matrices computed in our survey would provide guides to the structures to be initially tested in structural equation models" (p. 692). In addition, we should complete analysis of datasets published since those analyzed by Carroll. I propose establishing a common methodological link (to Carroll's original analysis) via the application of Carroll's exploratory factor analytic approach (using the specific methods outlined by Carroll, 1993) to post-Carroll datasets. In addition, the newer post-Carroll datasets could also be analyzed via confirmatory methods. Reanalysis of Carroll's 460+ datasets with contemporary procedures (viz., CFA), combined with both CFA and Carroll EFA-oriented exploratory procedures of newer datasets, will help elucidate the validity of current and proposed revisions of the CHC or other proposed human cognitive ability taxonomies. Each of the proposed three CHC structural research strategies (i.e., retrospective CFA analysis of Carroll's original 460+ datasets; Carroll-designed EFA of contemporary datasets; CFA of contemporary datasets) alone would be a monumental undertaking by a single researcher or group of researchers—but this lofty goal can be attained.

4.1. A recent example: Johnson and Bouchard's VPR model

Recently Johnson and Bouchard published a series of studies in *Intelligence* (Johnson & Bouchard, 2005a,b; Johnson, Nijenhuis & Bouchard, 2007) that are consistent with the current call for a renewed focus on the investigation of structural models of intelligence via the application of CFA methods to datasets analyzed by Carroll as well as newer post-Carroll datasets. Although not specifically testing the validity of the combined CHC model, Johnson and Bouchard used CFA methods to compare versions of the Carroll, Cattell–Horn Gf–Gc, Vernon verbal–perceptual (Vernon, 1964, 1965) models to the Johnson and Bouchard Verbal–Perceptual-Rotation (VPR) model.[5] Support for the VPR model was presented via the CFA analyses of a post-Carroll data set (463 subjects in the *Minnesota Study of Twins Reared Apart* study; Johnson & Bouchard, 2005a), CFA analyses of a classic dataset (Thurstone & Thurstone, 1941) also analyzed by Carroll (1993), and CFA analysis of another old dataset (de Wolff & Buiten, 1963) not included in Carroll's synthesis. The particular findings in favor of (or against) the plausibility of the VPR, Carroll, Cattell–Horn, and Vernon models is not important here. The important point is that Johnson and Bouchard's program of research demonstrates the value of the primary thesis offered in this editorial—the need to continue to refine and extend the taxonomy of human cognitive abilities via the exploration of current viable models of human cognitive abilities (e.g., CHC, Carroll Three-Stratum, Extended Cattell–Horn Gf–Gc; VPR) in datasets analyzed by Carroll and datasets not included in Carroll's synthesis (e.g., de Wolff & Buiten, 1963) or datasets published since Carroll completed his work. I believe an additional important component of the work represented by Johnson and Bouchard would be the *backward linking* of their findings to Carroll's factor analysis synthesis (via the application of the specific EFA procedures used by Carroll) to the two new Johnson and Bouchard datasets.

5. The Human Cognitive Abilities (HCA) project

Until recently the major constraint to the first strategy I am recommending (i.e., retrospective reanalysis of Carroll's 460+ datasets) was the lack of a centralized collection of the correlation matrices originally analyzed by Carroll. This constraint is currently being removed by the Woodcock-Muñoz Foundation's Human Cognitive Abilities (WMF HCA) project.[6] The WMF HCA project is an ongoing set of activities focused on electronically archiving, for historical purposes and secondary data analysis, as many of Carroll's 460+ correlation matrices as possible. The WMF HCA project currently focuses on two sets of activities. The first focus is the electronic data entry of the correlation matrices from Carroll's original printouts (and from select recovered disk files) and associated publications. The second is the development of a free web-based dataset archive repository and retrieval system by which independent researchers can access these materials.

The origins of the WMF HCA project lie in an initial archive project started in 2002 by the current author, Director of the Institute for Applied Psychometrics (IAP). Through a fortuitous sequence of events, I came to possess the original printouts for all analysis used in (Carroll, 1993) work.[7] Not only do the printouts contain the EFA summaries that are available for purchase (on disk) from Cambridge University Press, but they also include (a) detailed output of file pre-processing, (b) extended statistical output, (c) many traditional EFA solutions (e.g., principal factor models with orthogonal or oblique rotations) and interpretations that have never been published, (d) handwritten notes by Carroll, and (e) hand plotted scree-plots. More importantly, the original correlation matrices were included within the extended factor analysis output for most all analyses. In addition, I was fortunate to secure electronic copies of some of the original correlation files used in Carroll's work. In addition, Dr. Carroll taught me to use his self-written EFA software programs. As a result, IAP began the process of preserving and making accessible the 460+ Carroll correlation matrices that served as a primary cornerstone of the current CHC taxonomy. The HCA project was later transferred to WMF. All current archiving activities are now part of the WMF Human Cognitive Abilities project.

5.1. Description of the WMF HCA system

The current HCA Data Archive system is simple and can be accessed via three methods. A clickable visual–graphic mind map system can be accessed at http://www.iapsych.com/wmfhcaarchive/map.htm. If a more traditional web page organization and navigation system is desired, the user can click on the *Home* link at the top of the visual–graphic mind map. A complete outline format can be accessed by clicking on the *Table of Contents* link. Users can toggle between the different navigation modes via the three options in the upper right hand corner of each home page.

The WMF HCA Data Archive is an evolving resource. Updated versions are posted periodically when new correlation matrices and related publications are posted. Currently the WMF HCA Data Archive includes the following major sections:

[5] It is interesting to note that, similar to other recent *Intelligence* articles that do not mention the CHC framework, the models of Carroll and Cattell–Horn are prominently recognized and featured. Johnson and Bouchard state that "the Cattell–Horn and especially its successor the Carroll model are currently the models on which consensus tends to rest" (p. 80).

[6] The WMF HCA home page can be found at http://www.woodcock-munoz-foundation.org/r-HCAProject.html.

[7] Truth be known, a large number of green-lined, tractor-feed old style computer printouts, neatly organized and indexed in massive blue blinders, together with a large portion of Carroll's professional book collection, where precariously close to being thrown into the garbage (computer printouts) or sold as used books by the University of Minnesota library. The fortuitous call I received from the library staff, to help decide on how best to dispose of the material, lead to my serendipitous discovery and recovery of the computer printouts.

1. Overview of the Woodcock-Muñoz Foundation's (WMF) Human Cognitive Abilities (HCA) Project. This section includes historical and background information.
2. Archive procedures for Carroll's (1993) data sets. This section describes how to use the archive system, a complete dataset bibliography, acknowledgements, and disclaimer statements.
3. HCA project communications and announcements. This section includes project contact information. A link to the WMF HCA listserv is also included. The WMF HCA listserv is an open listserv where intelligence scholars can stay abreast of WMF HCA project progress. When new data sets, original manuscripts, or reports are added to the WMF HCA web-based archive, announcements are shared via the listserv. Requests for assistance from listserv members (e.g., finding old manuscripts) are also distributed via the WMF HCA listserv. Currently this is an announcement (newsletter) list only. It might eventually evolve into a discussion list.
4. Dataset sections/branches. Alphabetically organized branches (e.g., Data sets: ADEV01 to ARNO01 is one branch) store the archived datasets and original publications. Each dataset is represented by a separate sub-branch or section. Using the abbreviations employed by Carroll (1993), each dataset analysis is listed using Carroll's dataset code system (e.g., THOR21; Thorndike, (1936). Factor analysis of social and abstract intelligence. *Journal of Educational Psychology, 27*, 231–233.). For each listing two hyperlinks are provided.
   a. Correlation matrix: Clicking this dataset hyperlink allows the user to view a simple Excel-based copy of the respective correlation matrix. Users can save the file to their computer hard drive, convert it to the required file format (e.g., SYSTAT, SPSSPC), and commence with secondary analysis of the matrix.
   b. Original publication: Clicking this dataset hyperlink provides the user access to a PDF copy of the original research report (if available) from which Carroll secured the studies correlation matrix for analysis. This PDF file can either be viewed on-line and/or saved to the user's computer hard drive.

6. Concluding comments

The CHC taxonomy rests on the shoulders of numerous psychometric giants. Two of the most prominent giants in the field of intelligence, Horn and Carroll, remind us that contemporary intelligence scholars have a responsibility to improve upon, refine, and extend the current model. The CHC framework is "an open-ended empirical theory to which future tests of as yet unmeasured or unknown abilities could possibly result in additional factors at one or more levels in Carroll's hierarchy" (Jensen, 2004, p. 5). The availability of most of Carroll's originally analyzed 460+ correlation matrices provides a rare and important opportunity to refine Carroll's conclusions (as well as related cognitive models; e.g., Cattell–Horn Extended Gf–Gc theory; Johnson and Bouchard's VPR theory) via the application of contemporary analytic methods to historical datasets, and to link and extend this work into the future via the analysis of contemporary datasets.

According to Jensen (2004):

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

I concur with Jensen's characterization of Carroll's work as a magnum opus. However, I believe his work should not be viewed as the grand finale of the psychometric era, but instead, it should be viewed as the pivotal landmark or tipping point that provided the first working map of the human cognitive ability terrain, a terrain warranting additional exploration and refined cartographic efforts. I urge intelligence scholars to continue the emerging trend of integrating past and current research within a taxonomy with a common nomenclature (viz., CHC theory). The WMF HCA project is another small step in this direction. It is hoped that the WMF HCA Data archive stimulates individuals, groups of individuals, and organizations (e.g., ISIR, APA, AERA) to continue building on the work of the giants of intelligence. From their shoulders we are pointed in the proper direction in our search for an ever-evolving map of human intelligence.

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Kevin S. McGrew is Research Director for the Woodcock-Muñoz Foundation (WMF), Director of the Institute for Applied Psychometrics (IAP), Associate Director for Measurement Learning Consultants (MLC), and is a Visiting Professor in Educational Psychology at the University of Minnesota.