THE CATTELL-HORN-CARROLL THEORY OF COGNITIVE ABILITIES

The Cattell-Horn-Carroll (CHC) theory of cognitive abilities is the most comprehensive and empirically supported psychometric theory of the structure of cognitive abilities to date. It represents the integrated works of Raymond Cattell, John Horn, and John Carroll (Alfonso, Flanagan, & Radwan, 2005; Horn & Blankson, 2005; McGrew, 2005; Schneider & McGrew, 2012). Because it has an impressive body of empirical support in the research literature (e.g., developmental, neurocognitive, outcome-criterion) it is used extensively as the foundation for selecting, organizing, and interpreting tests of intelligence and cognitive abilities (e.g., Flanagan, Alfonso, & Ortiz, 2012; Flanagan, Ortiz, & Alfonso, 2007). Most recently, it has been used for classifying intelligence and achievement batteries and neuropsychological tests to: (a) facilitate interpretation of cognitive performance; and (b) provide a foundation for organizing assessments for individuals suspected of having a learning disability (Flanagan, Alfonso, Mascolo, & Sotelo-Dynega, 2012; Flanagan, Alfonso, Ortiz, & Dynda, 2010; Flanagan, Ortiz, & Alfonso, in press). Additionally, CHC theory is the foundation on which most new and recently revised intelligence batteries were based (see Flanagan & Harrison, 2012 for comprehensive coverage of these batteries). A brief overview of the evolution of CHC theory follows.

Fluid–Crystallized (*Gf-Gc*) Theory

The original *Gf-Gc* theory was a dichotomous conceptualization of human cognitive ability put forth by Raymond Cattell in the early 1940s. Cattell based his theory on the factor-analytic work of Thurstone conducted in the 1930s. Cattell believed that Fluid Intelligence (*Gf*) included inductive and deductive reasoning abilities that were influenced by biological and neurological factors as well as incidental learning through interaction with the environment. He postulated further that Crystallized Intelligence (*Gc*) consisted primarily of acquired knowledge abilities that reflected, to a large extent, the influences of acculturation (Cattell, 1957, 1971).

In 1965, John Horn expanded the dichotomous *Gf-Gc* model to include four additional abilities, including visual perception or processing (*Gv*), short-term memory (Short-term Acquisition and Retrieval—SAR or *Gsm*), long-term storage and retrieval (Tertiary Storage and Retrieval—TSR or *Glr*), and speed of processing (*Gs*). Later he added auditory processing ability (*Ga*) to the theoretical model and refined the definitions of *Gv*, *Gs*, and *Glr* (Horn, 1968; Horn & Stankov, 1982).

In the early 1990s, Horn added a factor representing an individual's quickness in reacting (reaction time) and making decisions (decision speed). The acronym or code for this factor is *Gt* (Horn, 1991). Finally, quantitative (*Gq*) and broad reading-writing (*Grw*) factors were added to the model based on the research of Horn (e.g., 1991) and Woodcock (1994), respectively. Based largely on the results of Horn's thinking and research, *Gf-Gc* theory expanded into an eight-factor model that became known as the Cattell-Horn *Gf-Gc* theory (Horn, 1991; see Horn and Blankson, 2005, for a comprehensive review of Horn's contribution to *Gf-Gc* theory).

Carroll's Three-Stratum Theory

In his review of the extant factor-analytic research literature, Carroll differentiated factors or abilities into three strata that varied according to the "relative variety and diversity of variables" (Carroll, 1997, p. 124) included at each level. The various *G* abilities are the most prominent and recognized abilities of the model. They are classified as broad or stratum II abilities and include abilities such as *Gf* and *Gc*, the two original factors. According to Carroll (1993), *broad* abilities represent "basic constitutional and long standing characteristics of individuals that can govern or influence a great variety of behaviors in a given domain" and they vary in their emphasis on process, content, and manner of response (p. 634). Broad abilities, like *Gf* and *Gc*, subsume a large number of narrow or stratum I abilities of which approximately 70 have been identified (Carroll, 1993, 1997). *Narrow* abilities "represent greater specializations of abilities, often in quite specific ways that reflect the effects of experience and learning, or the adoption of particular strategies of performance" (Carroll, 1993, p. 634). The broadest or most general level of ability in the *Gf-Gc* model is represented by stratum III, located at the apex of Carroll's (1993) hierarchy. This single cognitive ability, which subsumes both broad (stratum II) and narrow (stratum I) abilities, is interpreted as representing a general factor (i.e., *g*) that is involved in complex higher-order cognitive processes (Gustaffson & Undheim, 1996; Jensen, 1997; McGrew & Woodcock, 2001).

It is important to note that the abilities within each level of the hierarchical *Gf-Gc* model typically display nonzero positive intercorrelations (Carroll, 1993; Gustafsson & Undheim, 1996). For example, the different stratum I (narrow) abilities that define the various *Gf-Gc* domains are correlated positively and to varying degrees. These intercorrelations give rise to and allow for the estimation of the stratum II (broad) ability factors. Likewise, the positive nonzero correlations among the stratum II (broad) *Gf-Gc* abilities allow for the estimation of the stratum III (general) *g* factor. The positive factor intercorrelations within each level of the *Gf-Gc* hierarchy indicate that the different *Gf-Gc* abilities do not reflect completely independent (uncorrelated or orthogonal) traits. However, they can, as is evident from the vast body of literature that supports their existence, be reliably distinguished from one another and therefore represent unique, albeit related, abilities (see Keith & Reynolds, 2012).

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Similarities and Differences Between the Cattell-Horn Model and the Carroll Model

Simplified versions of the Cattell-Horn and Carroll models of the structure of abilities (i.e., where the narrow abilities are omitted) are presented together in Figure C.6, which shows a number of important similarities and differences between the two models. In general, these models are similar in that they both include multiple broad abilities with similar descriptions (e.g., *Gs*) and similar classification of narrow abilities. However there are four major structural differences between the Cattell-Horn and Carroll models.

First, Carroll's theory includes *g* (global or general ability) at stratum III and the Cattell-Horn theory does not, as these theorists disagreed over the existence of an overarching intellectual ability. This dispute is an ongoing debate in the field (see Schneider & McGrew, 2012 for a discussion on the existence of *g*). Second, in the Cattell-Horn model, *Gq* is comprised of quantitative knowledge and quantitative reasoning; however, Carroll classified quantitative reasoning as a narrow ability subsumed by *Gf*. Third, the Cattell-Horn theory includes a distinct broad reading/writing (*Grw*) factor, whereas Carroll's theory includes reading and writing as narrow abilities subsumed by *Gc*. Fourth, the Cattell-Horn and the Carroll models differ in their treatment of certain narrow memory abilities. Carroll combined both short-term memory and the narrow abilities of associative, meaningful, and free-recall memory with learning abilities under (*Gy*). Horn (1991) made a distinction between immediate apprehension (e.g., short-term memory span) and storage and retrieval abilities.

The First Generation of CHC Theory

Notwithstanding the important differences between the Cattell-Horn and the Carroll models, in order to realize the practical benefits of using theory to guide test selection, organization, and interpretation, it is necessary to define a single taxonomy—one that can be used to classify ability tests. A first effort to create a single taxonomy for this purpose was an integrated Cattell-Horn and Carroll model proposed by McGrew (1997). McGrew and Flanagan (1998) subsequently presented a slightly revised integrated model, which was further refined by Flanagan et al. (2000). The integrated model presented by McGrew and colleagues was accepted by both John Horn and John Carroll and thus became known as the Cattell-Horn-Carroll (CHC) theory, reflecting the order in which these theorists made their contributions. The original integration of the Cattell-Horn *Gf-Gc* theory and Carroll's three-stratum theory, or simply CHC theory, is presented in Figure C.7. This figure depicts the original structure of CHC theory and reflects the manner in which the Cattell-Horn and Carroll models have been integrated. In this figure, CHC theory includes 10 broad cognitive abilities, which are subsumed by over 70 narrow abilities.

Latest Refinements to CHC Theory

A paramount feature of the CHC theory is that it is not static, but rather a dynamic model that is continuously reorganized and restructured based on current research. Recently, Schneider and McGrew (2012) conducted an extensive review on CHC theory by (1) analyzing the

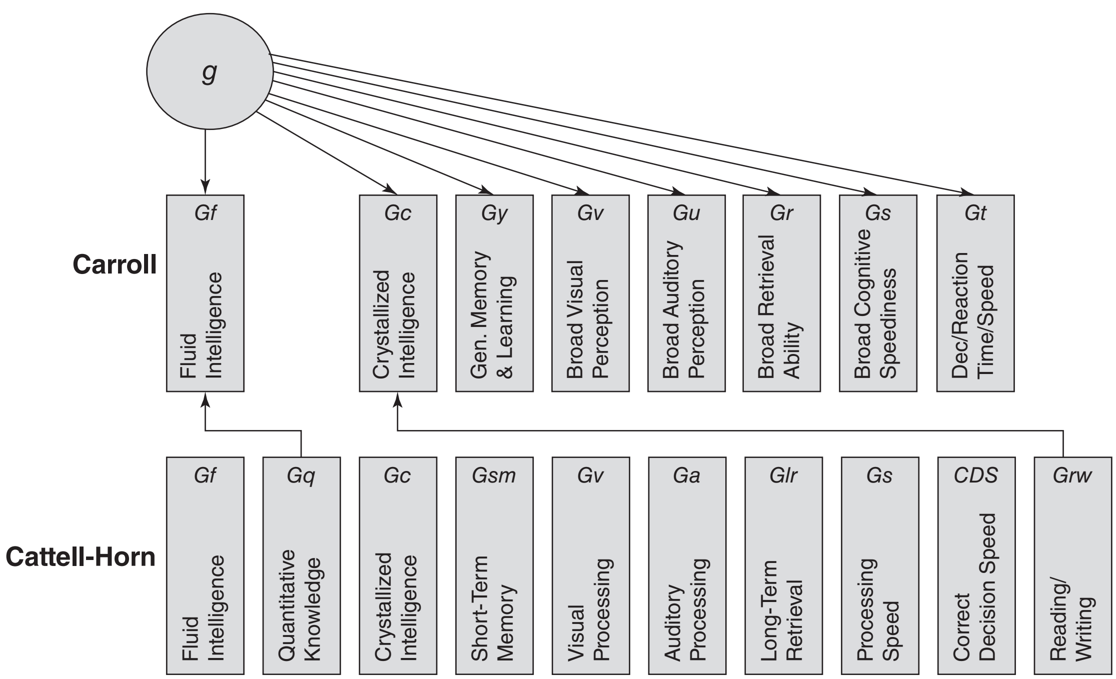

Figure C.6. Comparison of Cattell-Horn *Gf-Gc* theory and Carroll's Three-Stratum theory. *Source*: Flanagan & McGrew (1997).

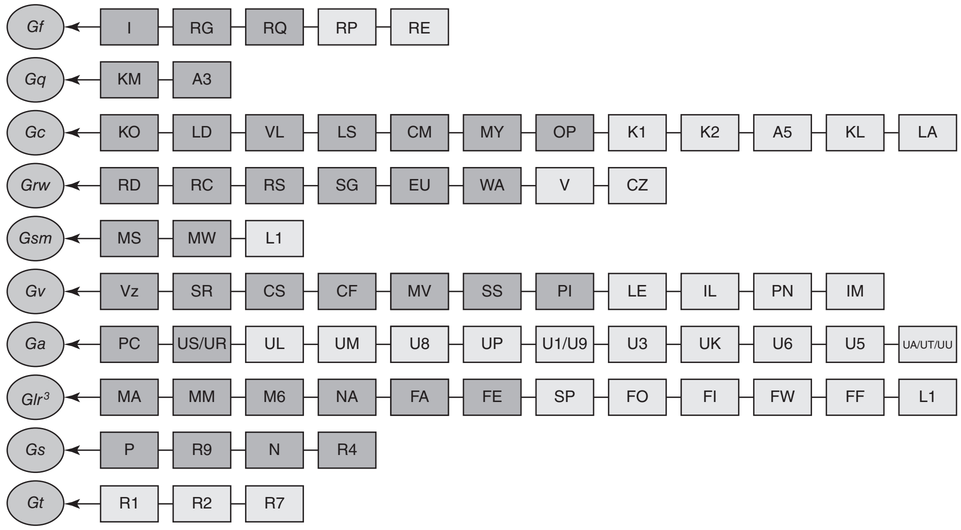

Figure C.7. Cattell-Horn-Carroll (CHC) theory. *Source*: Flanagan & McGrew (1997).

current theory and potential errors, (2) reviewing whether contemporary intellectual research validates or refutes the CHC model, (3) redefining constructs to be more meaningful for clinicians, (4) adding, deleting, and restructuring the broad and narrow abilities within the model, and (5) highlighting which aspects of the model are more central to CHC theory. While a thorough explanation and description of the changes made to CHC theory is beyond the scope of this entry, the interested reader is referred to Schneider and McGrew (2012).

The current model of CHC theory is presented in Figure C.8. In this model, CHC theory includes 16 broad cognitive abilities, which are subsumed by over 80 narrow abilities. The ovals represent broad abilities and rectangles represent narrow abilities. The darker rectangles represent those narrow abilities that are most consistently represented on tests of cognitive and academic abilities. Additionally, the overall *g* or general ability is omitted from this figure intentionally due to space limitations. The conceptual groupings of abilities (i.e., reasoning, acquired knowledge, memory and efficiency, sensory, motor, and speed and efficiency) were suggested by Schneider and McGrew and provide an integrated framework of both cognitive and neuropsychological perspectives (Flanagan et al., 2010). The CHC theory represented a culmination of more than 60 years of factor-analysis research in the psychometric tradition. However, in addition to structural evidence, there are other sources of validity evidence, some quite substantial, that support CHC theory. Prior to defining the broad and narrow abilities that comprise CHC theory, a brief overview of the validity evidence in support of this structure of cognitive abilities is presented.

A Network of Validity Evidence in Support of CHC Theory

It is beyond the scope of this entry to provide a fully detailed account and review of all the validity evidence currently available in support of the CHC structural model as well as the broad and narrow ability constructs it encompasses. The interested reader is referred to Carroll (1993, 2005), Flanagan and Harrison (2012), Horn and Blankson (2005), and Schneider & McGrew (2012) for a more thorough discussion.

Briefly, the CHC structure of abilities is supported by factor-analytic (i.e., structural) evidence as well as developmental, neurocognitive, and heritability evidence (see Horn & Blankson, 2005). Additionally, there is a mounting body of research available on the relations between the broad cognitive CHC abilities and many academic outcomes (summarized in Flanagan et al., 2006; McGrew & Wendling, 2010), and occupational outcomes (Ackerman & Heggestad, 1997; McGrew & Flanagan, 1998). Furthermore, studies have shown that the factor structure of CHC theory is invariant across the lifespan (Bickley, Keith, & Wolfe, 1995; Keith, 2005; Woodcock et al., 2001) and across gender, ethnic, and cultural groups (e.g., Carroll, 1993; Gustafsson & Balke, 1993; Keith, 1997, 1999). In general, CHC theory is based on a more extensive network of validity evidence than other contemporary multidimensional ability models (see Daniel, 1997; Schneider & McGrew, 2012; Sternberg & Kaufman, 1998).

Given the breadth of empirical support for the CHC structure of intelligence, it provides one of the most useful frameworks for designing and evaluating psychoeducational batteries, including intelligence, achievement, and neuropsychological tests (Flanagan et al., in press; Keith & Reynolds, 2012). Moreover, in light of the well-established structural validity of CHC theory, external validity support for the various CHC constructs, derived through sound research methodology, can be used confidently to guide test interpretation (see Bensen, 1998; Evans, Floyd, McGrew, & Leforgee, 2002; Flanagan, 2000; Floyd, Evans, & McGrew, 2003; Vanderwood, McGrew, Flanagan, & Keith, 2002).

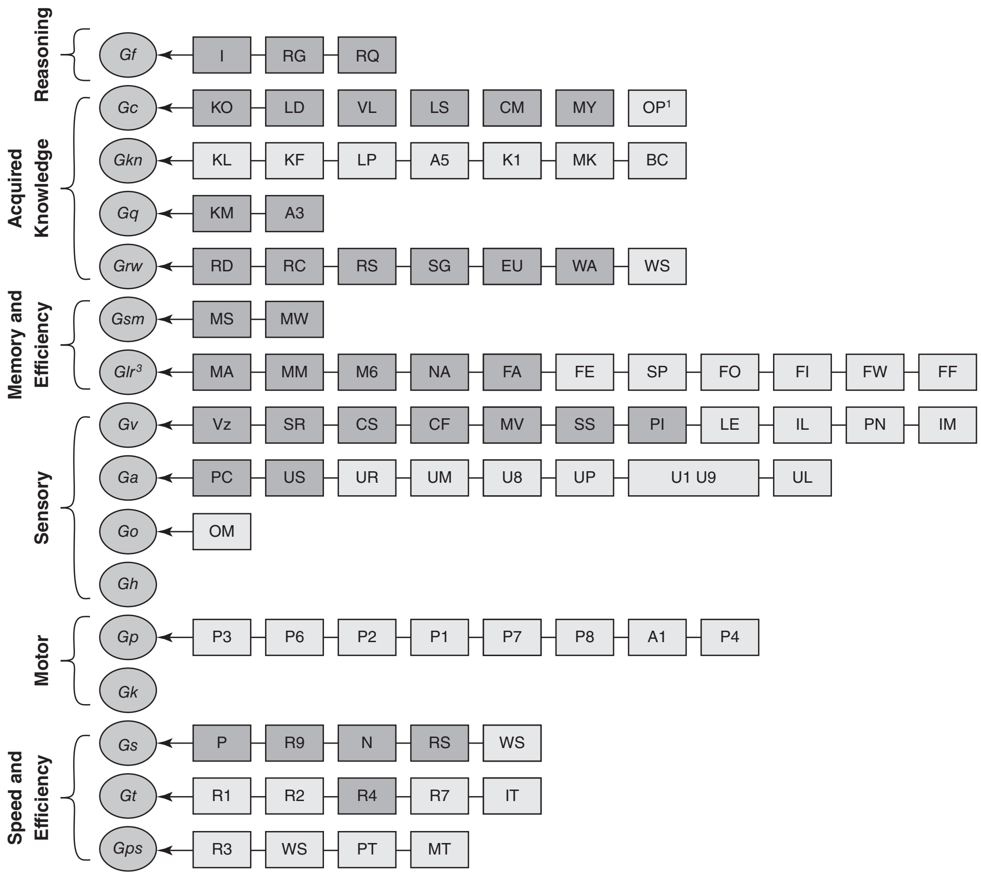

Figure C.8. Current and expanded CHC theory of cognitive abilities. *Source*: Flanagan & McGrew (1997).

As previously mentioned, it is important to recognize that research related to CHC theory is not static. Rather, research on the hierarchical structure of abilities (within the *Gf-Gc* and now CHC framework) has been systematic, steady, and mounting for decades. Definitions of the broad and narrow abilities currently comprising CHC theory are presented in the next section.

Broad and Narrow CHC Ability Definitions

These definitions presented here were derived from an integration of the writings of Carroll (1993), Gustafsson and Undheim (1996), Horn (1991), McGrew (1997, 2005), and Schneider and McGrew (2012). The narrow ability definitions are presented in Tables C.1 through C.15.

Fluid Intelligence (*Gf*)

Fluid intelligence refers to mental operations that an individual uses when faced with a relatively novel task that cannot be performed automatically. These mental operations may include forming and recognizing concepts, perceiving relationships among patterns, drawing inferences, comprehending implications, problem solving, extrapolating, and reorganizing or transforming information. *Gf* can also be described as "deliberate but flexible control of attention to solve novel, 'on-the-spot' problems that cannot be performed by relying exclusively on previous learned habits, schemas, and scripts" (Schneider & McGrew, 2012, p. 111). Inductive and deductive reasoning are generally considered to be the hallmark narrow ability indicators of *Gf*. Although most practitioners would agree that this ability is typically not measured directly by individually administered achievement batteries, some tests of achievement clearly involve the use of specific *Gf* abilities. For example, many tests of reading comprehension require individuals to draw inferences from the text. Aside from general inductive and deductive reasoning abilities, *Gf* also subsumes more specific types of reasoning, most notably Quantitative Reasoning (RQ). Unlike the other narrow *Gf* abilities, RQ is more directly related to formal instruction and classroom-related experiences. Definitions of the narrow abilities subsumed by *Gf* are presented in Table C.1.

Crystallized Intelligence (*Gc*)

Crystallized intelligence refers to the breadth and depth of a person's acquired knowledge and skills that are valued by one's culture. This store of primarily verbal or language-based knowledge represents those abilities that

Table C.1. Narrow *Gf* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Fluid Intelligence (*Gf*)	
Induction (I)	Ability to discover the underlying characteristic (e.g., rule, concept, process, trend, class membership) that governs a problem or a set of materials.
General Sequential Reasoning (RG)	Ability to start with stated rules, premises, or conditions, and to engage in one or more steps to reach a solution to a novel problem.
Quantitative Reasoning (RQ)	Ability to inductively and deductively reason with concepts involving mathematical relations and properties.

Note. Definitions were derived from Carroll (1993) and Schneider and McGrew (2012).

have been developed largely through the "investment" of other abilities during educational and general life experiences (Horn & Blankson, 2005).

Gc includes both declarative (static) and procedural (dynamic) knowledge. Declarative knowledge includes factual information, comprehension, concepts, rules, and relationships, especially when the information is verbal in nature. Declarative knowledge is held in long-term memory and is activated when related information is in working memory (*Gsm*). Procedural knowledge refers to the process of reasoning with previously learned procedures in order to transform knowledge. For example, a child's knowledge of his or her street address would reflect declarative knowledge, whereas a child's ability to find his or her way home from school would require procedural knowledge (Gagne, 1985).

A rather unique aspect of *Gc* not seen in the other broad abilities is that it appears to be both a store of acquired knowledge (e.g., lexical knowledge, general information, information about culture) as well as a collection of processing abilities (e.g., communication ability, listening ability). The narrow ability of General Information (K0), for example, is clearly a repository of learned information, whereas the narrow Listening Ability (LS) appears to represent the ability to effectively comprehend and process information presented orally. Although research is needed to discern the nature of acquired knowledge versus processing abilities within the *Gc* domain, assessment of *Gc* should pay close attention to the narrow abilities that define this broad domain. Despite the interrelatedness of all narrow abilities under *Gc*, there may well be times when focus on the abilities that are more process oriented, as opposed to those that are knowledge oriented, is most important, and vice versa. Definitions of the narrow abilities subsumed by *Gc* are presented in Table C.2.

Table C.2. Narrow *Gc* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Crystallized Intelligence (*Gc*)	
General (verbal) Information (*K0*)	Range of general knowledge.
Language Development (LD)	General development, or the understanding of words, sentences, and paragraphs (not requiring reading), in spoken native language skills.
Lexical Knowledge (VL)	Extent of vocabulary that can be understood in terms of correct word meanings.
Listening Ability (LS)	Ability to listen and comprehend oral communications.
Communication Ability (CM)	Ability to speak in real-life situations (e.g., lecture, group participation) in an adult-like manner.
Grammatical Sensitivity (MY)	Knowledge or awareness of the grammatical features of the native language.
Oral Production and Fluency (OP)	More specific or narrow oral communication skills than reflected by Communication Ability (CM).

Note. Definitions were derived from Carroll (1993) and Schneider and McGrew (2012).

General (Domain-Specific) Knowledge (*Gkn*)

General (domain-specific) knowledge (*Gkn*) is the "depth, breadth, and mastery of specialized knowledge (knowledge not all members of a society are expected to have)" (Schneider & McGrew, 2012, p. 123). This newly introduced broad ability was created from four narrow abilities previously accounted for in the *Gc* domain (i.e., Foreign Language [KL], Geography Achievement [A5], General Science Information [K1], and Knowledge of Culture [K2]) because they represent the acquired knowledge from specialized domains. This specialized knowledge is usually developed through an individual's work experience, hobbies, or passions. The *Gkn* broad ability is unique in that it is a domain that does not have a true *G* ability because the aggregates are of specific and distinct abilities. Furthermore, an individual should not be assessed in comparison with same age-peers in the general populations, but rather individuals who possess the same specialized knowledge base. For example, a sociologist's knowledge of human social behavior (i.e., *Gkn* narrow ability of sociology) should be compared only to other sociologists, not the general public. Since an almost infinite number of specialized areas of knowledge exist, the broad ability of *Gkn* contains an unlimited number of narrow abilities. However, several examples of *Gkn* narrow abilities are listed and defined below in Table C.3 (Schneider & McGrew, 2012).

Table C.3. Narrow *Gkn* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
General (Domain-Specific) Knowledge (*Gkn*)	
Foreign Language Proficiency (KL)	Similar to Language Development (LD) but for a foreign language.
Knowledge of Signing (KF)	Knowledge of finger-spelling and signing (e.g., American Sign Language).
Skill in Lip-reading (LP)	Competence in the ability to understand communication from others by watching the movements of their mouths and expressions.
Geography Achievement (A5)	Range of geographic knowledge.
General Science Information (K1)	Range of scientific knowledge (e.g., biology, physics, engineering, mechanics, electronics).
Mechanical Knowledge (MK)	Knowledge about the function, terminology, and operation of ordinary tools, machines, and equipment.
Knowledge of Behavioral Content (BC)	Knowledge or sensitivity to nonverbal human communication/interaction systems (e.g., facial expressions and gestures).

Note. Definitions were derived from Carroll (1993) and Schneider and McGrew (2012).

Quantitative Knowledge (*Gq*)

Quantitative knowledge represents an individual's "depth and breadth of knowledge related to mathematics" (Schneider & McGrew, 2012, p. 127). The *Gq* store of acquired knowledge represents the ability to use quantitative information and manipulate numeric symbols. *Gq* abilities are typically measured by achievement tests. For example, most comprehensive tests of achievement include measures of math calculation, applied problems (or math problem solving), and general math knowledge. Although some intelligence batteries measure aspects of *Gq* (e.g., Arithmetic on the Wechsler Scales, Quantitative Reasoning on the SB5), they typically do not measure this ability comprehensively.

It is important to understand the difference between *Gq* and the Quantitative Reasoning (RQ) ability that is subsumed by *Gf*. On the whole, *Gq* represents an individual's store of acquired mathematical knowledge, including the ability to perform mathematical calculations (i.e., procedural knowledge). Quantitative Reasoning represents only the ability to reason inductively and deductively when solving quantitative problems. *Gq* is most evident when a task requires mathematical skills (e.g., addition, subtraction, multiplication, division) and general mathematical knowledge (e.g., knowing what the square-root symbol means). RQ, on the other hand, would be required to solve for a missing number in a number-series task (e.g., 3, 6, 9, ___), for example. Three narrow abilities are listed and defined under *Gq* in Table C.4.

Table C.4. Narrow *Gq* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Quantitative Knowledge (*Gq*)	
Mathematical Knowledge (*KM*)	Range of general knowledge about mathematics.
Mathematical Achievement (A3)	Measured mathematics achievement.

Note. Definitions were derived from Carroll (1993) and Schneider and McGrew (2012).

Reading/Writing Ability (*Grw*)

Reading/Writing ability is an acquired store of knowledge that includes basic reading, reading fluency, and writing skills required for the comprehension of written language and the expression of thought via writing. It includes both basic abilities (e.g., reading decoding and fluency, spelling) and complex abilities (e.g., comprehending written discourse, writing a story). Like *Gq*, *Grw* is considered to be an "achievement" domain and, therefore, has been measured traditionally (and almost exclusively) by tests of academic achievement. In Carroll's (1993) three-stratum model, eight narrow reading and writing abilities are subsumed by *Gc* in addition to other abilities. In the CHC model, six of the eight narrow abilities define the broad *Grw* ability (verbal language comprehension [V] and cloze ability [CZ] were dropped because they were not distinct abilities), and an additional measure (writing speed [WS]) was included. These *Grw* narrow abilities are defined in Table C.5.

Short-Term Memory (*Gsm*)

Short-term memory is the ability to apprehend and hold information in immediate awareness and then use it within a few seconds. *Gsm* is a limited-capacity system, as most individuals can retain only seven "chunks" of information (plus or minus two chunks) in this system at one time. An example of *Gsm* is the ability to remember a telephone number long enough to dial it. Given the limited amount of information that can be held in short-term memory, information is typically retained for only a few seconds before it is lost. As most individuals have experienced, it is difficult to remember an unfamiliar telephone number for more than a few seconds unless one consciously uses a cognitive learning strategy (e.g., continually repeating or rehearsing the numbers) or other mnemonic device. When a new task requires an individual to use his or her *Gsm* abilities to store new information, the previous information held in short-term memory is either lost or must be stored in the acquired stores of knowledge (i.e., *Gc*, *Gq*, *Grw*) through the use of *Glr*.

In the original CHC model, *Gsm* subsumes the narrow ability of working memory, which has received

Table C.5. Narrow *Grw* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Reading/Writing (*Grw*)	
Reading Decoding (RD)	Ability to recognize and decode words or pseudowords in reading.
Reading Comprehension (RC)	Ability to comprehend connected discourse during reading.
Reading Speed (RS)	Time required to silently read a passage or series of sentences as quickly as possible.
Spelling Ability (SG)	Ability to spell. (Not clearly defined by existing research.)
English Usage Knowledge (EU)	Knowledge of writing in the English language with respect to capitalization, punctuation, usage, and spelling.
Writing Ability (WA)	Ability to write with clarity of thought, organization, and good sentence structure. (Not clearly defined by existing research).
Writing Speed (WS)	The ability to copy or generate text quickly.

Note. Definitions were derived from Carroll (1993) and Schneider and McGrew (2012).

considerable attention in the cognitive psychology literature (see Kane, Bleckley, Conway, & Engle, 2001). However, in the recent revision of CHC theory, Schneider and McGrew renamed the narrow ability to Working Memory Capacity (MW), as it was more reflective of the tasks on cognitive and intelligence tests. Schneider and McGrew acknowledge that the current state of scientific literature on memory is immense, and therefore only relevant constructs are currently included in the CHC model. However, as research illuminates the correlations among different memory constructs and academic skills, it is likely that *Gsm* narrow abilities will continue to evolve. Definitions of the current narrow abilities subsumed by *Gsm* are presented in Table C.6.

Long-Term Storage and Retrieval (*Glr*)

Long-term storage and retrieval is the ability to store information in and fluently retrieve new or previously acquired information (e.g., concepts, ideas, items, names) from long-term memory. *Glr* abilities have been prominent in creativity research, where they have been referred to as idea production, ideational fluency, or associative fluency. It is important not to confuse *Glr* with *Gc*, *Gq*, and *Grw*, which represent to a large extent an individual's stores of acquired knowledge. Specifically, *Gc*, *Gq*, and *Grw* represent what is stored in long-term memory, whereas Glr is the efficiency by which this information is initially stored in and later retrieved from long-term memory.

Table C.6. Narrow *Gsm* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Short-Term Memory (*Gsm*)	
Memory Span (MS)	Ability to attend to and immediately recall temporally ordered elements in the correct order after a single presentation.
Working Memory (MW)	Ability to temporarily store and perform a set of cognitive operations on information that requires divided attention and the management of the limited capacity of short-term memory.

Note. Definitions were derived from Carroll (1993) and Schneider and McGrew (2012).

It is also important to note that different processes are involved in *Glr* and *Gsm*. Although the word *long-term* frequently carries with it the connotation of days, weeks, months, and years in the clinical literature, long-term storage processes can begin within a few minutes or hours of performing a task. Therefore, the time lapse between the initial task performance and the recall of information related to that task is not necessarily of critical importance in defining *Glr*. However, the broad abilities of *Glr* and *Gsm* are highly interdependent, which is noted in the recent revisions of CHC theory. In the present CHC model, 11 narrow memory and fluency abilities are included under *Glr* (see Table C.7).

Visual Processing (*Gv*)

Visual processing (*Gv*) is the ability to generate, perceive, analyze, synthesize, store, retrieve, manipulate, transform, and think with visual patterns and stimuli (Lohman, 1994), or more succinctly, "the ability to make use of simulated mental imagery to solve problems" (Schneider & McGrew, 2012, p. 129). These abilities are measured frequently by tasks that require the perception and manipulation of visual shapes and forms, usually of a figural or geometric nature (e.g., a standard block design task). An individual who can mentally reverse and rotate objects effectively, interpret how objects change as they move through space, perceive and manipulate spatial configurations, and maintain spatial orientation would be regarded as having a strength in *Gv* abilities. *Gv* abilities are also related significantly to higher-level mathematics achievement (e.g., geometry and trigonometry; Casey, Nuttall, & Pezaris, 1997; Hegarty & Kozhevnikov, 1999). The various narrow abilities subsumed by *Gv* are listed and defined in Table C.8.

Auditory Processing (*Ga*)

In the broadest sense, auditory processing is the "ability to detect and process meaningful nonverbal information in sound" (Schneider & McGrew, 2012, p. 131). Specifically,

Table C.7. Narrow *Glr* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Long-Term Storage and Retrieval (*Glr*)	
Associative Memory (MA)	Ability to recall one part of a previously learned but unrelated pair of items when the other part is presented (i.e., paired-associative learning).
Meaningful Memory (MM)	Ability to recall a set of items where there is a meaningful relation between items or the items comprise a meaningful story or connected discourse.
Free-Recall Memory (M6)	Ability to recall as many unrelated items as possible, in any order, after a large collection of items is presented.
Naming Facility (NA)	Ability to rapidly produce names for concepts when presented with a pictorial or verbal cue.
Associational Fluency (FA)	The ability to rapidly produce a series of original or useful ideas related to a particular concept.
Expressional Fluency (FE)	The ability to rapidly think of different ways of expressing an idea.
Sensitivity to Problems/Alternative Solution Fluency (SP)	The ability to rapidly think of a number of solutions to particular practical problem.
Originality/ Creativity (FO)	Ability to rapidly produce original, clever, and insightful responses (expressions, interpretations) to a given topic, situation, or task.
Ideational Fluency (FI)	Ability to rapidly produce a series of ideas, words, or phrases related to a specific condition or object. Quantity, not quality, is emphasized.
Word Fluency (FW)	Ability to rapidly produce words that have specific phonemic, structural, or orthographic characteristics (independent of word meanings).
Figural Fluency (FF)	Ability to rapidly draw or sketch several examples or elaborations when given a starting visual or descriptive stimulus.

Note. Definitions were derived from Carroll (1993) and Schneider and McGrew (2012).

Table C.8. Narrow *Gv* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Visual Processing (*Gv*)	
Visualization (Vz)	The ability to perceive complex patterns and mentally simulate how they might look when transformed (e.g., rotated, changed in size, partially obscured).
Speeded Rotation (Spatial Relations; SR)	The ability to solve problems quickly by using mental rotation of simple images.
Closure Speed (CS)	Ability to quickly combine disconnected, vague, or partially obscured visual stimuli or patterns into a meaningful whole, without knowing in advance what the pattern is.
Flexibility of Closure (CF)	Ability to find, apprehend, and identify a visual figure or pattern embedded in a complex visual array, when knowing in advance what the pattern is.
Visual Memory (MV)	Ability to form and store a mental representation or image of a visual stimulus and then recognize or recall it later.
Spatial Scanning (SS)	Ability to accurately and quickly survey a spatial field or pattern and identify a path through the visual field or pattern.
Serial Perceptual Integration (PI)	Ability to apprehend and identify a pictorial or visual pattern when parts of the pattern are presented rapidly in serially or successive order.
Length Estimation (LE)	Ability to accurately estimate or compare visual lengths and distances without using measurement instruments.
Perceptual Illusions (IL)	Ability to resist being affected by perceptual illusions involving geometric figures.
Perceptual Alternations (PN)	Consistency in the rate of alternating between different visual perceptions.
Imagery (IM)	Ability to vividly mentally manipulate abstract spatial forms. (Not clearly defined by existing research.)

Note. Definitions were derived from Carroll (1993) and Schneider and McGrew (2012).

auditory processing is the ability to perceive, analyze, and synthesize patterns among auditory stimuli, and to discriminate subtle nuances in patterns of sound (e.g., complex musical structure) and speech when presented under distorted conditions. Although *Ga* abilities do not require the comprehension of language (*Gc*) per se, they are important in the development of language skills (Liberman, Shankweiler, Fischer, & Carter, 1974; McGrew & Wendling, 2010; Wagner & Torgesen, 1987). *Ga* subsumes most of those abilities referred to as "phonological awareness/processing." Tests that measure these abilities (e.g., phonetic coding tests) are found typically on achievement batteries. In fact, the number of tests specifically designed to measure phonological processing has increased significantly in recent years, presumably as a result of the consistent finding that phonological awareness/processing appears to be the core deficit in individuals with reading difficulties (e.g., Morris et al., 1998; Vellutino, Scanlon, & Lyon, 2000; Velluntino & Scanlon, 2002). However, as can be seen from the list of narrow abilities subsumed by *Ga* (Table C.9), this domain is very broad, extending far beyond phonetic coding ability.

Table C.9. Narrow *Ga* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Auditory Processing (*Ga*)	
Phonetic Coding (PC)	Ability to hear phonemes distinctly. This ability is also referred to as phonological processing, phonological awareness, and phonemic awareness.
Speech Sound Discrimination (US)	Ability to detect differences in speech sounds under conditions of little distraction or distortion.
Resistance to Auditory Stimulus Distortion (UR)	Ability to understand speech and language that has been distorted or masked in one or more ways.
Memory for Sound Patterns (UM)	Ability to retain on a short-term basis auditory events such as tones, tonal patterns, and voices.
Maintaining and Judging Rhythm (U8)	Ability to recognize and maintain a musical beat.
Absolute Pitch (UP)	Ability to perfectly identify the pitch of tones.
Musical Discrimination and Judgment (U1 U9)	Ability to discriminate and judge tonal patterns in music with respect to melodic, harmonic, and expressive aspects (phrasing, tempo, harmonic complexity, intensity variations)
Sound Localization (UL)	Ability to localize heard sounds in space.

Note. Definitions were derived from Carroll (1993) and Schneider and McGrew (2012).

Olfactory Abilities (*Go*)

Olfactory abilities refer to the "abilities to detect and process meaningful information in odors" (Schneider & McGrew, 2012, p. 132). This broad ability does not account for how sensitive one is to smell, but rather the cognitive processes an individual uses to interpret information from the olfactory system. While the current CHC theory lists only one *Go* narrow ability (Olfactory Memory [OM], see Table C.10), research suggests that other narrow abilities (e.g., episodic odor memory, odor identification) may exist. *Go* was only recently added to the CHC model; therefore, more research is needed to identify additional narrow abilities or whether it is appropriately included in the model.

Table C.10. Narrow *Go* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Olfactory Abilities (*Go*)	
Olfactory Memory (OM)	Ability to recognize previously encountered distinctive odors.

Note. Definition was derived from Carroll (1993) and Schneider and McGrew (2012).

Table C.11. Narrow *Gh* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Tactile Abilities (*Gh*)	
Note: There are no well-supported cognitive ability factors within *Gh* yet.	Tactile abilities (*Gh*) can be defined as the ability to detect and process meaningful information in haptic (touch) sensations.

Note. Description from Schneider and McGrew (2012).

Tactile Abilities (*Gh*)

Tactile abilities are defined as "the abilities to detect and process meaningful information in haptic (touch) sensations" (Schneider & McGrew, 2012, p. 133). Similar to *Go*, *Gh* is not how sensitive one is to touch, but how one uses cognitive processes to interpret touch. Due to limited operational definitions of tactile abilities, there is currently little evidence supporting *Gh* narrow abilities. However, it is likely that further research will identify narrow abilities, such as tactile memory or knowledge of textures. (See Table C.11.)

Psychomotor Abilities (*Gp*)

Psychomotor abilities are known as the "abilities to perform physical body motor movements (e.g., movement of fingers, hands, legs) with precision, coordination, or strength" (Schneider & McGrew, 2012, p. 134). Although *Gp* is not typically measured on cognitive and intelligence tests, psychomotor abilities are an important factor measured in neuropsychological assessments. For example, the Dean-Woodcock Neuropsychological Battery (Dean & Woodcock, 2003) includes several tasks designed to measure gross and fine motor skills (Flanagan et al., 2010). Psychomotor abilities are critical in understanding typical and atypical neuropsychological functioning, along with identifying any neurological or neuropsychological disorders. A list and definitions of current *Gp* narrow abilities can be found in Table C.12.

Kinesthetic Abilities (*Gk*)

Kinesthetic abilities are known as the "abilities to detect and process meaningful information in proprioceptive sensations" (Schneider & McGrew, 2012, p. 133). Proprioception refers to one's awareness of body position and movement (Westen, 2002). Although there is currently a limited understanding of *Gk* narrow abilities, we can infer they may include abilities such as a yogi being able to feel the correct body position in a pose, or a swimmer being able to demonstrate an adjustment in arm position that improves technique.

Table C.12. Narrow *Gp* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Psychomotor Abilities (*Gp*)	
Static Strength (P3)	Ability to exert muscular force to move (push, lift, pull) a relatively heavy or immobile object.
Multilimb Coordination (P6)	Ability to make quick specific or discrete motor movements of the arms or legs.
Finger Dexterity (P2)	Ability to make precisely coordinated movements of the fingers (with or without the manipulation of objects).
Manual Dexterity (P1)	Ability to make precisely coordinated movements of a hand or a hand and the attached arm.
Arm–Hand Steadiness (P7)	Ability to precisely and skillfully coordinate arm–hand positioning in space.
Control Precision (P8)	Ability to exert precise control over muscle movements, typically in response to environmental feedback (e.g., changes in speed or position of object being manipulated).
Aiming (AI)	Ability to precisely and fluently execute a sequence of eye–hand coordination movements for positioning purposes.
Gross Body Equilibrium (P4)	Ability to maintain the body in an upright position in space or regain balance after balance has been disturbed.

Note. Definitions were derived from Carroll (1993) and Schneider and McGrew (2012).

Processing Speed (*Gs*)

Processing speed or mental quickness is often mentioned when talking about intelligent behavior (Nettelbeck, 1994). Processing speed is the "ability to perform simple, repetitive cognitive tasks quickly and fluently" (Schneider & McGrew, 2012, p. 119). These cognitive tasks often require maintained focused attention and concentration; therefore, "attentive speediness" encapsulates the essence of *Gs*. *Gs* is measured typically by fixed-interval timed tasks that require little in the way of complex thinking or mental processing (e.g., the Wechsler Animal Pegs, Symbol Search, Cancellation, and Digit Symbol/Coding tests).

Recent interest in information-processing models of cognitive functioning has resulted in a renewed focus on *Gs* (Kail, 1991; Lohman, 1989, McGrew, 2005). A central construct in information-processing models is the idea of limited processing resources (e.g., the limited capacities of short-term and working memory): "Many cognitive activities require a person's deliberate efforts and people are limited in the amount of effort they can allocate. In the face of limited processing resources, the speed of processing is critical because it determines in part how rapidly limited resources can be reallocated to other cognitive tasks" (Kail, 1991, p. 492). Woodcock (1993) likens *Gs* to a valve in a water pipe. The rate at which water flows in the pipe (i.e., *Gs*) increases when the valve is opened wide and decreases when the valve is partially closed. Five different narrow speed-of-processing abilities are subsumed by *Gs* in the present CHC model (see Table C.13).

Table C.13. Narrow *Gs* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Processing Speed (*Gs*)	
Perceptual Speed (P)	Ability to rapidly search for and compare known visual symbols or patterns presented side-by-side or separated in a visual field.
Rate-of-Test-Taking (R9)	Ability to rapidly perform tests which are relatively easy or that require very simple decisions.
Number Facility (N)	Ability to rapidly and accurately manipulate and deal with numbers, from elementary skills of counting and recognizing numbers to advanced skills of adding, subtracting, multiplying, and dividing numbers.
Reading Speed (Fluency) (RS)	Time required to silently read a passage or series of sentences as quickly as possible.
Writing Speed (Fluency) (WS)	The rate at which words or sentences can be generated or copied.

Note. Definitions were derived from Carroll (1993) and Schneider and McGrew (2012).

Decision Speed/Reaction Time (*Gt*)

In addition to *Gs*, both Carroll and Horn included a second broad speed ability in their respective models of the structure of abilities. Processing Speed or Decision Speed/Reaction Time (*Gt*), as proposed by Carroll, subsumes narrow abilities that reflect an individual's quickness in reacting (reaction time) and making decisions (decision speed). *Gt* is also considered as the "speed of making very simple decisions or judgments when items are presented one at a time" (Schneider & McGrew, 2012, p. 120). Correct Decision Speed (CDS), proposed by Horn as a second speed ability (*Gs* being the first), is typically measured by recording the time an individual requires to provide an answer to problems on a variety of tests (e.g., letter series, classifications, vocabulary; Horn, 1988, 1991). Because Correct Decision Speed appeared to be a much narrower ability than *Gt*, it is subsumed by *Gt* in CHC theory.

It is important not to confuse *Gt* with *Gs*. *Gt* abilities reflect the immediacy with which an individual can react to stimuli or a task (typically measured in seconds or parts of seconds), whereas *Gs* abilities reflect the ability to work

Table C.14. Narrow *Gt* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Decision/Reaction Time or Speed (*Gt*)	
Simple Reaction Time (R1)	Reaction time to the presentation of a single visual or auditory stimulus.
Choice Reaction Time (R2)	Reaction time to one of two or more alternative stimuli, depending on which alternative is signaled.
Semantic Processing Speed (R4)	Reaction time when the decision requires some encoding and mental manipulation of stimulus content.
Mental Comparison Speed (R7)	Reaction time where the stimuli must be compared for a particular attribute.
Inspection Time (IT)	The speed at which differences in stimuli can be perceived.

Note. Definitions were derived from Carroll (1993) and Schneider and McGrew (2012).

quickly over a longer period of time (typically measured in intervals of 2 to 3 minutes). Being asked to read a passage (on a self-paced scrolling video screen) as quickly as possible and, in the process, touch the word *the* with a stylus pen each time it appears on the screen, is an example of *Gs*. The individual's *Gs* score would reflect the number of correct responses (taking into account errors of omission and commission). In contrast, *Gt* may be measured by requiring a person to read the same text at his or her normal rate of reading and press the space bar as quickly as possible whenever a light is flashed on the screen. In this latter paradigm, the individual's score is based on the average response latency or the time interval between the onset of the stimulus and the individual's response. Table C.14 includes descriptions of the narrow abilities subsumed by *Gt*.

Psychomotor Speed (*Gps*)

Psychomotor speed is the "speed and fluidity with which physical body movements can be made" (Schneider & McGrew, 2012, p. 121). Psychomotor speed tasks are rarely measured on assessment batteries, with the exception of finger-tapping tasks in some neuropsychological tests. There are currently four narrow abilities of *Gps*, which are described in Table C.15.

Conclusion

The Cattell-Horn-Carroll theory is the most researched, empirically supported, and comprehensive hierarchical psychometric framework of the structure of cognitive abilities. It reflects a major review and reanalysis of the world's literature on individual differences in cognitive abilities, collected over most of a century (Carroll, 1993).

Table C.15. Narrow *Gps* Stratum I Ability Definitions

Narrow Stratum I Name (Code)	Definition
Psychomotor Speed (*Gps*)	
Speed of Limb Movement (R3)	The speed of arm and leg movement.
Writing Speed (Fluency) (WS)	The speed at which written words can be copied.
Speed of Articulation (PT)	Ability to rapidly perform successive articulations with the speech musculature.
Movement Time (MT)	The time taken to physically move a body part (e.g., a finger) to make the required response. MT may also measure the speed of finger, limb, or multilimb movements or vocal articulation (diadochokinesis; Greek for "successive movements") (Carroll, 1993).

Note. Definitions were derived from Carroll (1993) and Schneider and McGrew (2012).

The culmination of the monumental contributions of Raymond Cattell, John Horn, and John Carroll, know as CHC theory, will continue to define the taxonomy of cognitive differential psychology for decades to come.

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