CHAPTER 4

The Cattell–Horn–Carroll Model of Intelligence

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The Cattell–Horn–Carroll (CHC) theory of cognitive abilities consists of two components. First, it is a *taxonomy*[1] of cognitive abilities. However, it is no mere list. The second component, embedded in the taxonomy, is a set of theoretical explanations of how and why people differ in their various cognitive abilities. This chapter is intended to make CHC theory useful and usable to practitioners. It also aims to provide a reflective account of CHC theory's historical roots and evolution; an introspective meditation on its current status, with a candid discussion of its virtues and shortcomings; and a tempered but hopeful projection of its future.

THE IMPORTANCE OF TAXONOMIES

> SOCRATES: . . . but in these chance utterances were involved two principles, the essence of which it would be gratifying to learn, if art could teach it.
>
> PHAEDRUS: What principles?
>
> SOCRATES: That of perceiving and bringing together in one idea the scattered particulars, that one may make clear by definition the particular thing which he wishes to explain.
>
> PHAEDRUS: And what is the other principle, Socrates?
>
> SOCRATES: That of dividing things again by classes, where the natural joints are, and not trying to break any part, after the manner of a bad carver.
>
> —PLATO, *Phaedrus* (§ 265d)

A useful classification system shapes how we view complex phenomena by illuminating consequential distinctions and obscuring trivial differences. A misspecified classification system orients us toward the irrelevant and distracts us from taking productive action. Imagine if we had to use astrological classification systems for personnel selection, college admissions, jury selection, or clinical diagnosis. The scale of inefficiency, inaccuracy, and injustice that would ensue boggles the mind. Classification is serious business.

Much hinges on classification systems being properly aligned with our purposes. Consider the role that the periodic table of elements has played in the physical sciences. First arranged by Mendeleev in 1869, it is not just a random collection of different elements. Embedded in the periodic table are a number of organizing principles (e.g., number of protons, valence electrons) that not only *reflected* the theoretical advances of the 19th century, but also *propelled* discoveries in physics and chemistry to the present day.

A well-validated taxonomy of cognitive abilities will not resemble the periodic table of elements, but it should have the same function of organizing past findings and revealing holes in our knowledge warranting exploration. It should give researchers a common frame of reference and nomenclature. It should suggest criteria by which disagreements can be settled. For now, there is no taxonomy of cognitive abilities that commands the same level of authority as the periodic table of elements. Should one emerge, it will happen via the only means any scientific theory should: The theoretical framework will withstand all attempts to knock it down. Because it is a systematic synthesis of hundreds of studies spanning more than a century of empirical investigations of cognitive abilities, CHC theory is put forward as a candidate for a common framework for cognitive ability researchers (McGrew, 2009). All are invited to help build it, and anyone is entitled to try to knock it down by subjecting it to critical tests of its assumptions.

THE EVOLUTION OF THE CHC THEORY OF COGNITIVE ABILITIES

The CHC theory of intelligence is the "tent" that houses the two most prominent psychometric theoretical models of human cognitive abilities (Daniel, 1997, 2000; Kaufman, 2009; McGrew, 2005, 2009; Snow, 1998; Sternberg & Kaufman, 1998). CHC theory represents the integration of the Horn–Cattell Gf-Gc theory (Horn & Noll, 1997; see Horn & Blankson, Chapter 3, this volume) and Carroll's three-stratum theory (Carroll, 1993; see Carroll, Appendix to this volume).

The study of cognitive abilities is intimately linked to historical developments in exploratory and confirmatory factor analysis, the primary methodological engine that has driven the psychometric study of intelligence for over 100 years (Cudek & MacCallum, 2007). However, it is also important to recognize that non-factor-analytic research, in the form of heritability, neurocognitive, developmental, and outcome prediction (occupational and educational) studies, provides additional sources of validity evidence for CHC theory (Horn, 1998; Horn & Noll, 1997). Space limitations necessitate a focus only on the factor-analytic portions of the contemporary psychometric approach to studying individual differences in human cognitive abilities.

The historical development of CHC theory is presented in the timeline depicted in Figure 4.1. The first portion of this chapter is organized according to the events in this timeline.

Early Psychometric Heritage

> The developers of intelligence tests were not as narrow minded as they are often made out to be; and, as a necessary corollary, nor are we as clever as some would have it. Those who have not themselves read widely from the books and articles of luminaries such as Binet, Spearman, Thorndike, and Stern are not so much condemned to repeat history (as Santayana claimed) as they are to say and write silly things.
>
> —LOHMAN (1997, p. 360)

Historical accounts of the evolution of the psychometric approach to the study of human individual differences abound (e.g., see Brody, 2000; Carroll, 1993; Cudeck & MacCallum, 2007; Horn & Noll, 1997; see also Wasserman, Chapter 1, this volume).[2] We cannot possibly convey the full extent of the depth, breadth, and subtlety of thought characteristic of most of the great early theorists. We have tried to avoid Lohman's curse of saying silly things by consulting the original sources. A good rule of thumb is that whenever an important historical theory appears laughable when summarized, the stupidity is in the summary, not the source.

As illustrated in Figure 4.1, Francis Galton is generally considered the founder of the field of individual differences via his interests in measuring, describing, and quantifying human differences and the genetics of geniuses. The study of individual differences in reaction time is credited with originating in German psychologist Wilhelm Wundt's lab. Wundt is reported to have had little interest in the study of individual differences. However, an American student of Wundt's, James McKeen Cattell, was interested in the topic and is credited with coining the term *mental test* (Cattell, 1890).

Another student of Wundt's, Charles Spearman, had a similar interest in measuring individual differences in sensory discrimination (reflecting the influence of Galton). Spearman (1904) developed a "two-factor theory" (a general intelligence factor, *g*, plus specific factors) to account for correlations between measures of academic achievement, reasoning, and sensory discrimination (see Figure 4.2).

Carroll (1993) suggested that Spearman's theory might be better called a "one-general-factor theory." Spearman is generally credited with introducing the notion of factor analysis to the study of human abilities. Spearman and his students eventually began to study other possible factors beyond *g*. The Spearman–Holzinger model (Carroll, 1993), which was based on Holzinger's development of the bifactor method, suggested *g* plus five group factors (Spearman, 1939). In the final statement of Spearman's theories, Spearman and Wynn-Jones (1950) recognized many group factors: verbal

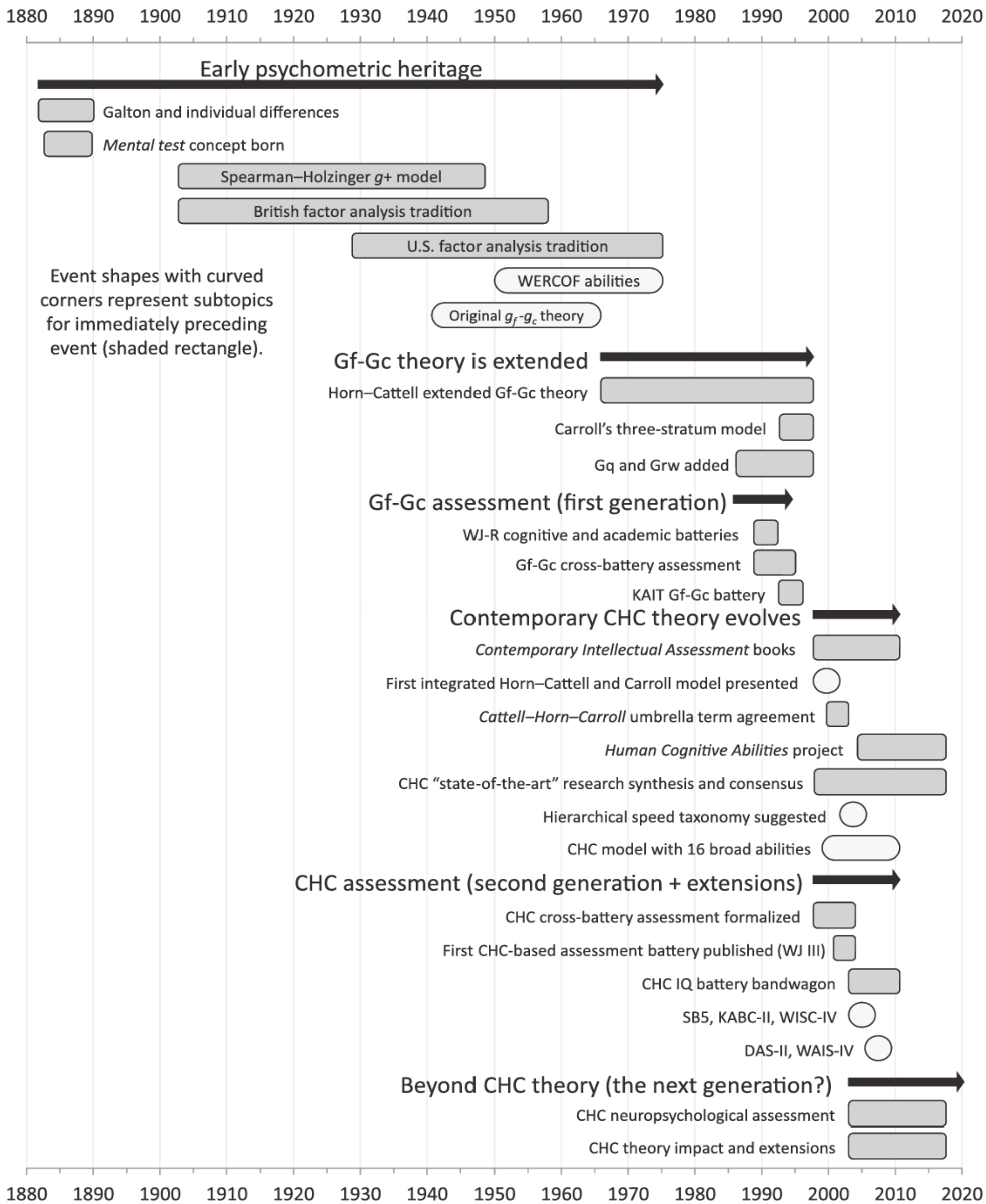

FIGURE 4.1. The evolution of CHC intelligence theory and assessment methods: A timeline.

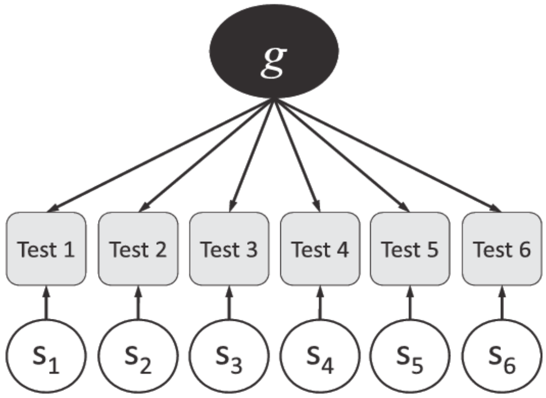

FIGURE 4.2. Spearman's two-factor theory.

(Gc), spatial (Gv), motor (Gp), memory (Glr and Gsm), mathematics (Gq), speed (Gs), and several others (abbreviations denote approximate correspondence with CHC theory). The definition and issues surrounding the construct of *g* are discussed in greater detail in Box 4.1.

Reflecting the seminal influence of Spearman, the British factor analysis tradition (see Figure 4.1) suggested that the lion's share of the variance of human intelligence was attributable to *g* and to very small group factors. The importance of the broader group factors was considered meager (Gustafsson, 1988).

Across the ocean, the factor analysis tradition in the United States focused on the use of early forms of multiple factor analysis that did not readily identify a *g* factor. Instead, the correlations among measures produced correlated (oblique) first-order factors that were typically factor analyzed again to produce second-order factors.

L. L. Thurstone is to factor analysis in the United States what Spearman is to the British tradition of factor analysis. Thurstone's theory posited seven to nine primary mental abilities (PMAs) that were independent of a higher-order *g* factor.[3] Thurstone's (1938) PMA theory included induction (I), deduction (D), verbal comprehension (V), associative memory (Ma), spatial relations (S), perceptual speed (P), numerical facility (N), and word fluency (Fw). Thurstone (1947) was willing to accept the possible existence of a *g* (general factor) above his PMAs. The primary Spearman–Holzinger/Thurstone disagreement was the perceived difference in relative importance of the first-order PMAs and the second-order *g* factor (Carroll, 1993).

From the 1940s to 1960s, numerous factor-analytic studies of human cognitive abilities were conducted using variants of Thurstone's multiple-factors method. The period from 1952 to approximately 1976 was particularly productive, as the Educational Testing Service (ETS) sponsored a series of activities and conferences with the goal to develop a standard kit of reference tests to serve as established factor "markers" in future factor analysis studies (Carroll, 1993). Summaries of the large body of PMA-based factor research suggested over 60 possible separate PMAs (Ekstrom, French, & Harman, 1979; French, 1951; French, Ekstrom, & Price, 1963; Guilford, 1967; Hakstian & Cattell, 1974; Horn, 1976). The ETS factor–reference group work established the well-replicated common factors (WERCOF) abilities (Horn, 1989). Carroll's (1993) model is strongly influenced by the 1976 edition of the ETS standard kit (Ekstrom et al., 1979). Of its 23 primary abilities, 16 have the same names in Carroll's list of stratum I (narrow) abilities. The remaining 7 ETS factors are all in Carroll's (1993) model but have different names.

Gf-Gc Theory Is Conceived

Raymond Cattell was a student of Spearman's who applied Thurstone-style factor-analytic methods to the WERCOF/PMA datasets.

Cattell (1941, 1943) concluded that Spearman's *g* was best explained by splitting *g* into general *fluid* (g_f) and general *crystallized* (g_c) intelligence. The positing of a hierarchical model of two equally important broad abilities (Gf and Gc) above the numerous lower-order WERCOF abilities represented the formal beginning of the Horn–Cattell Gf-Gc theory.[4]

The genius of Gf-Gc theory is not the idea that there was more than one factor, or that there were specifically two factors (both ideas had been previously articulated). The astounding achievement of the original Gf-Gc theory is that Cattell (1941, 1943) was able to describe the nature of both factors, model how Spearman's *g* arose from Gf and Gc, and explain many diverse and previously puzzling empirical observations. Most importantly, the findings have largely withstood the test of time. Cattell's (1943) first printed description of both factors is worth quoting here:

> Fluid ability has the character of a purely general ability to discriminate and perceive relations between any fundaments, new or old. It increases until adolescence and then slowly declines. It is associated with the action of the whole cortex. It is responsible for

BOX 4.1. Does *g* Exist?

The question of whether *g* exists causes more rancor amongst cognitive ability researchers than perhaps any other. For some, the mere mention of *g* brings to mind a rapid succession of frightful images that start with bureaucratic abuses of IQ tests and proceed straight to Hitler. For others, the fight for *g* is about preserving the last sanctuary of reason and liberty from the perverse and pervasive influence of showboating do-gooder muddleheads with a secret lust for worldwide domination via progressive education. Who can stay silent when the cords of one's identity are strained and the fate of nations hangs in the balance? Honor, dignity, pride, and justice demand otherwise. Of course, from time to time there are impassioned pleas for dispassionate discourse, but the sirens of serenity are seldom seductive.

Positive Manifold

In the beginning, Spearman (1904) discovered what has come to be known as the *positive manifold*—the tendency for all tests of mental ability to be positively correlated. Thousands of replicating studies later, Spearman's observation remains uncontroversial. What was then, what is now, and what will be controversial for a long time is Spearman's explanation for the positive manifold.

In many ways, Spearman's explanation was the simplest explanation possible. The reason that all tests are positively correlated is that performance on all tests is influenced by a common cause, *g*. Each test is influenced both by *g* and by its own *s* (specific) factor (see Figure 4.2). Spearman's two-factor theory has a misleading name because there are not just two factors; there is one general factor and as many *s* factors as there are tests. Thus the two-factor theory is really a theory about two different kinds of factors, general and specific.

Is *g* an Ability?

The controversy about the theoretical status of *g* may have less fire and venom if some misunderstandings are clarified. First, Spearman did not believe that performance on tests was affected by *g* and only *g*. He always accepted that specific factors were often important, and came to appreciate group factors (Spearman & Wynn-Jones, 1950). Second, Spearman (1927, p. 92) always maintained, even in his first paper about *g* (Spearman, 1904, p. 284), that *g* might consist of more than one general factor. Third, Spearman did not consider *g* to be an ability, or even a thing (Spearman, 1934, pp. 312–313; Spearman & Wynn-Jones, 1950, p. 25). Yes, you read that last sentence correctly.

Horn (see Horn & Blankson, Chapter 3, this volume), Carroll (1998), and Cattell (1943) may have had different ideas about the nature of psychometric *g*, but they were all in agreement with Spearman that factors derived from factor analysis should not be reified prematurely. However, they believed that it was still useful to observe regularities in data and to hypothesize causes of those regularities. Cattell explained it thus:

> Obviously "g" is no more resident in the individual than the horsepower of a car is resident in the engine. It is a concept derived from the relations between the individual and his environment. But what trait that we normally project into and assign to the individual is not? The important further condition is that the factor is not determinable by the individual and his environment but only in relation to a group and its environment. A test factor loading or an individual's factor endowment has meaning only in relation to a population and an environment. But it is difficult to see why there should be any objection to the concept of intelligence being given so abstract a habitation when economists, for example, are quite prepared to assign to such a simple, concrete notion as "price" an equally relational existence. (p. 19)

We, like Spearman and essentially all other researchers who study this matter, are not sure about what causes statistical *g*. However, we suspect that Jensen (Bock, Goode, & Webb, 2000, p. 29) is correct in his judgment that *g* is not an ability itself, but the sum total of all forces that cause abilities within the same person to be more similar to each other than they otherwise would have been. Forces that simultaneously affect the whole brain may include individual differences in many individual genes and gene complexes, differential exposure to environmental toxins (e.g., lead, mercury, mold), parasites, childhood diseases, blunt-force trauma, large strokes, malnutrition, substance abuse, and many other forces. Furthermore, societal forces can act to cause otherwise uncorrelated abilities to become correlated. High socioeconomic status gives some people greater access to all of the things that enhance brain functioning and greater protection from all of the things that harm the brain. Low socioeconomic status is associated with exposure to a whole host of risk factors that can damage the whole brain. Put together, these forces seem more than enough to create the observed positive manifold and the *g* factor that emerges from factor analysis. Clinically, we view measures of *g* to be a useful point of reference, much like magnetic north. However, when we explore unfamiliar places, we do not restrict our view to lines of longitude. We like to look about in all directions.

> the intercorrelations, or general factor, found among children's tests and among the speeded or adaptation-requiring tests of adults.
>
> Crystallized ability consists of discriminatory habits long established in a particular field, originally through the operation of fluid ability, but no longer requiring insightful perception for their successful operation. (p. 178)

Cattell's (1963) Gf-Gc investment theory addressed the question "Why do some people know much more than others?" Cattell believed that differences in people's breadth and depth of knowledge are the joint function of two kinds of influences. Low fluid intelligence limits the rate at which a person can acquire and retain new knowledge. People with high fluid intelligence have far fewer constraints on their ability to learn.

Whether Gf is high or low, most learning comes about by effort. There are many non-ability-related reasons why some people engage in the learning process more than others, including availability and quality of education, family resources and expectations, and individual interests and goals. All of these differences in time and effort spent on learning were called *investment* by Cattell (1987). Cattell's original (1941, 1943) Gf-Gc theory has an explanation for the positive manifold: Gf and Gc are both general ability factors, and these factors are strongly correlated because Gf, in part, causes Gc via investment. However, for people with low Gf, investments in learning pay smaller dividends than for people with high Gf. This causes Gf and Gc to be highly correlated, and psychometric *g* emerges in the resulting positive manifold (see Figure 4.3).

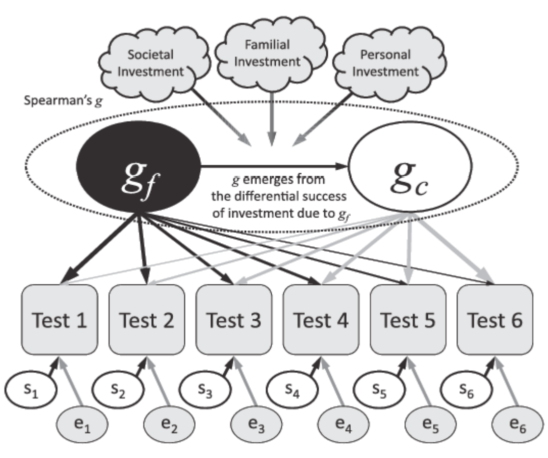

FIGURE 4.3. Cattell's investment theory.

Gf-Gc Theory Is Extended

However brilliant Cattell's original (1941, 1943) theory was, it remained a post hoc explanation of existing data until the first deliberate empirical test of the theory was conducted by John Horn (Cattell, 1963).[5] Horn's (1965) dissertation (supervised by Cattell) provided support for Cattell's theory, but also proposed that it be significantly expanded. It can be said that Horn reconceptualized and upgraded several of Thurstone's (1938, 1947) PMAs[6] to be coequal with Cattell's two general factors (e.g., space = Gv). Horn, Cattell, and others then worked to subdivide each of the general factors into narrower abilities that were even more primary than Thurstone's PMAs.

Horn's (1965) doctoral dissertation expanded Gf-Gc theory to several broad ability factors (Gf, Gc, Gv, Gs, SAR, TSR; Horn & Cattell, 1966). The change in notation from g_f and g_c to Gf and Gc was deliberate because in the extended Gf-Gc theory both Gf and Gc are narrower concepts than their counterparts in Cattell's original theory (see Horn & Blankson, Chapter 3, this volume).

From approximately 1965 to the late 1990s, Horn, Cattell, and others published systematic programs of factor-analytic research confirming the original Gf-Gc model and adding new factors. By 1991, Horn had extended the Gf-Gc theory to include 9–10 broad Gf-Gc abilities: fluid intelligence (Gf), crystallized intelligence (Gc), short-term acquisition and retrieval (SAR or Gsm), visual intelligence (Gv), auditory intelligence (Ga), long-term storage and retrieval (TSR or Glr), cognitive processing speed (Gs), correct decision speed (CDS), and quantitative knowledge (Gq). Woodcock's (1990, 1993) broad-ranging factor-analytic reviews of clinical measures of cognitive abilities strongly suggested the inclusion of a reading/writing (Grw) ability.

Carroll's (1993) Principia: *Human Cognitive Abilities*

Human Cognitive Abilities: A Survey of Factor-Analytic Studies (Carroll, 1993) represents in the field of applied psychometrics a work similar in stature to other so-called "principia" publications in other fields (e.g., Newton's three-volume *The Mathematical Principles of Natural Philosophy*, or *Principia* as it became known; Whitehead & Russell's *Principia Mathematica*). Briefly, Carroll summarized a reanalysis of more than 460 different datasets that included nearly all the more important and classic factor-analytic studies of human cognitive abilities since the time of Spearman. This important development is labeled *Carroll's three-stratum model* in the CHC timeline (see Figure 4.1).

We are not alone in elevating Carroll's work to such a high stature. 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; emphasis in original). Horn (1998) described Carroll's (1993) work as a "tour de force summary and integration" that is the "definitive foundation for current theory" (p. 58); he also compared Carroll's summary to "Mendeleev's first presentation of a periodic table of elements in chemistry" (p. 58). Jensen (2004) stated that "on my first reading this tome, in 1993, I was reminded of the conductor Hans von Bülow's exclamation on first reading the full orchestral score of Wagner's *Die Meistersinger*, 'It's impossible, but there it is!'" (p. 4). Finally, according to Jensen,

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

The beauty of Carroll's (1993) book was that for the first time ever, an empirically based taxonomy of human cognitive abilities, based on the analysis (with a common method) of the extant literature since Spearman, was presented in a single, coherent, organized, systematic framework (McGrew, 2005, 2009). Briefly, Carroll proposed a three-tier model of human cognitive abilities that differentiates abilities as a function of breadth. At the broadest level (stratum III) is a general intelligence factor. Next in breadth are eight broad abilities that represent "basic constitutional and long-standing characteristics of individuals that can govern or influence a great variety of behaviors in a given domain" (Carroll, 1993, p. 634).

Stratum II includes the abilities of fluid intelligence (Gf), crystallized intelligence (Gc), general memory and learning (Gy), broad visual perception (Gv), broad auditory perception (Ga), broad retrieval ability (Gr), broad cognitive speediness (Gs), and reaction time/decision speed (Gt). Stratum I includes numerous narrow abilities subsumed by the stratum II abilities, which in turn are subsumed by the single stratum III *g* factor. Finally, Carroll recognized that his theoretical model built on the research of others, particularly Cattell and Horn. According to Carroll, the Horn–Cattell Gf-Gc model "appears to offer the most well-founded and reasonable approach to an acceptable theory of the structure of cognitive abilities" (p. 62).

In a sense, Carroll (1993) provided the field of intelligence with a much-needed "Rosetta stone" that would serve as a key for deciphering and organizing the enormous mass of literature on the structure of human cognitive abilities accumulated since the days of Spearman. Carroll's work was also influential in creating the awareness among intelligence scholars, applied psychometricians, and assessment professionals, that understanding human cognitive abilities required "three-stratum vision." As a practical benefit, Carroll's work provided a common nomenclature for professional communication—a nomenclature that would go "far in helping us all better understand what we are measuring, facilitate better communication between and among professionals and scholars, and increase our ability to compare individual tests across and within intelligence batteries" (McGrew, 1997, p. 171).

Gf-Gc Assessment: First Generation

The 1989 publication of the Woodcock–Johnson Psychoeducational Battery—Revised (WJ-R; Woodcock & Johnson, 1989), a revision of the original 1977 WJ battery (Woodcock, 1978; Woodcock & Johnson, 1977), represented the official "crossing over" of Gf- Gc theory to the work of applied practitioners, particularly those conducting assessments in educational settings. A personal account of the serendipitous events, starting in 1985, that resulted in the bridging of the intelligence theory–assessment gap can be found in the preceding edition of this chapter (McGrew, 2005), and additional historical context has been provided by Kaufman (2009).

Publication of the Horn–Cattell-Organized WJ-R Battery

The WJ-R test development blueprint was based on the Horn–Cattell extended Gf-Gc theory (McGrew, Werder, & Woodcock, 1991; Schrank, Flanagan, Woodcock, & Mascolo, 2002). The WJ-R represented the first individually administered, nationally standardized, clinical cognitive and achievement battery to close the gap between contemporary psychometric theory (i.e., Horn–Cattell Extended Gf-Gc theory) and applied assessment practice. According to Daniel (1997), the WJ-R was "the most thorough implementation of the multifactor model" (p. 1039) of intelligence. As a direct result of the publication of the WJ-R, "Gf-Gc as a second language" emerged vigorously in educational and school psychology training programs, journal articles, books, and psychological reports, and became a frequent topic on certain professional and assessment-related electronic listservs.

First Proposal of Gf-Gc Cross-Battery Assessment

In 1990, Richard Woodcock planted the seed for the idea of Gf-Gc "battery-free" assessment, in which a common Gf-Gc taxonomy for assessment and interpretation was deployed across *all* intelligence batteries. In his seminal article summarizing his analysis of a series of joint confirmatory factor analysis (CFA) studies of the major intelligence batteries, Woodcock demonstrated how individual tests from each intelligence battery mapped onto the broad abilities of Horn–Cattell extended Gf-Gc taxonomy. More importantly, Woodcock suggested that in order to measure a greater breadth of Gf-Gc abilities, users of other instruments should use "cross-battery" methods to fill their respective Gf-Gc measurement voids. Practitioners were no longer constrained to the interpretive structure provided by a specific intelligence battery (see Flanagan, Alfonso, & Ortiz, Chapter 19, this volume, for a summary of their cross-battery approach).

Contemporary CHC Theory Evolves

The *Contemporary Intellectual Assessment* Books

The collective influence of the Horn–Cattell extended Gf-Gc theory, Carroll's (1993) treatise, and the publication of the WJ-R was reflected in nine chapters' being devoted to, or including significant treatment of, the Horn–Cattell extended Gf-Gc and Carroll three-stratum theories in Flanagan, Genshaft, and Harrison's (1997) first edition of *Contemporary Intellectual Assessment: Theories, Tests, and Issues* (often referred to informally as the "CIA book"). This publication, as well as its second edition (Flanagan & Harrison, 2005), was another key theory-to-practice bridging event (see Figure 4.1). The current volume (the third edition) continues the tradition.

The original CIA book contributed to the evolution of CHC theory for three primary reasons. First, it was the first intellectual assessment text intended for university trainers and assessment practitioners that included introductory chapters describing both the Horn–Cattell and Carroll models by the theorists themselves (Horn & Noll, 1997; Carroll's chapter is reprinted as the Appendix to the present volume).

Second, the *first* published integration of the Horn–Cattell and Carroll models was articulated in a chapter by McGrew (1997). Furthermore, Flanagan and McGrew (1998) articulated the need for tests in intelligence batteries to be classified at both the stratum I (narrow) and stratum II (broad) Gf-Gc ability levels. However, to do so, a single taxonomy was needed—yet the two major models contained some differences.[7] Instead of selecting one model over the other, McGrew (1997, p. 152) presented a "synthesized Carroll and Horn–Cattell Gf-Gc framework."

Finally, the original CIA text included the first formal description of the assumptions, foundations, and operational principles for implementing Gf-Gc cross-battery assessment (Flanagan & McGrew, 1997). The cross-battery seed planted by Woodcock (1990) had blossomed, and the intelligence theory-to-practice gap had narrowed fast. The CHC "tipping point" had begun.[8]

Formal "Branding" and Infusion of CHC Theory in Research and Practice

CHC theory represents *both* the Horn–Cattell and Carroll models, in their respective splendor. Much like the term *information-processing theories*, which provides an overarching theoretical umbrella for a spectrum of very similar (yet different) theoretical model variations (Lohman, 2001), the term *CHC theory* serves the same function for the "variations on a Gf-Gc theme" by Horn–Cattell and Carroll, respectively. The historical details of the origin of the umbrella *Cattell–Horn–Carroll (CHC)* term are described in McGrew (2005).

The recognition and influence of the CHC taxonomic umbrella increased steadily after 1999 (McGrew, 2009), particularly in professional fields engaged in applied intellectual assessment. The

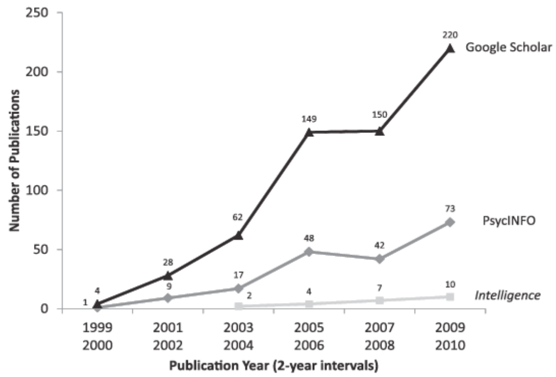

FIGURE 4.4. Number of publications including the terms *CHC* or *Cattell–Horn–Carroll* (by year) from two search sources.

adoption of the CHC umbrella model has been slower in publications in theoretical fields (e.g., *Intelligence*) outside the field of school psychology. As can be seen in Figure 4.4, the acceptance and use of the umbrella name *CHC theory* started in earnest in 2000–2001 and have steadily increased during the past decade.[9] It is clear that the professional discourse of intelligence theory and assessment literature is increasingly embracing CHC terminology.

CHC "State-of-the-Art" Research Syntheses

A major factor influencing the increasing recognition of the CHC framework has been a series of CHC "state-of-the-art" research syntheses (see Figure 4.1). In the second edition of the CIA text (Flanagan & Harrison, 2005), McGrew (2005) presented the most comprehensive historical treatment of the evolution of CHC theory. The second edition of the CIA included no fewer than 8 (of 29) chapters that specifically addressed the major components of CHC theory (McGrew, 2005, plus Horn & Blankson's and Carroll's chapters, reprinted here as Chapter 3 and the Appendix, respectively); CHC-grounded intelligence batteries (Elliott, 2005; Kaufman, Kaufman, Kaufman-Singer, & Kaufman, 2005; Roid & Pomplun, 2005; Schrank, 2005); and CHC theory's impact on test development and interpretation (Alfonso, Flanagan, & Radwan, 2005). CHC theory also received notable attention in chapters dealing with the history of intellectual assessment (Kamphaus, Winsor, Rowe, & Kim, 2005; Wasserman & Tulsky, 2005); information-processing approaches to intelligence test interpretation (Floyd, 2005); interventions for students with learning disabilities (Mather & Wendling, 2005); assessment of preschoolers (Ford & Dahinten, 2005), gifted children (McIntosh & Dixon, 2005), and those with learning disabilities (Flanagan & Mascolo, 2005); and the use of CFA in the interpretation of intelligence tests (Keith, 2005). The current volume continues this tradition.

An acknowledged limitation of Carroll's (1993, p. 579) three-stratum model was the fact that Carroll's inferences regarding the relations between different factors at different levels (strata) emerged from data derived from a diverse array of largely independent studies and samples (McGrew, 2005). None of Carroll's datasets included the necessary breadth of variables to evaluate, in a single analysis, the general structure of his proposed three-stratum model. An important contribution of McGrew's (2005) review was the synthesis of a significant number of exploratory and confirmatory factor-analytic investigations completed since the publication of Carroll's seminal work. The reader is referred to McGrew (2005) and McGrew and Evans (2004) for detailed summaries. One contribution of these reviews was the recognition of the potential for internal elaborations and refinements of CHC theory and for external extensions of CHC theory through the addition of new constructs, such as the broad abilities of general knowledge (Gkn), tactile abilities (Gh), kinesthetic abilities (Gk), olfactory abilities (Go), and psychomotor speed (Gps).

Of particular interest, but largely ignored during the past several years, was the conclusion that the speed domains of Gs and Gt might best be represented within the context of a hierarchically organized speed taxonomy with a *g*-speed factor at the apex (McGrew, 2005; McGrew & Evans, 2004). This conclusion has been echoed by Danthiir, Roberts, Schulze, and Wilhelm (2005), who, after conducting much of the research that suggests a multidimensional speed hierarchy, suggested that "one distinct possibility is that mental speed tasks form as complex a hierarchy as level (i.e., accuracy) measures from psychometric tasks, with a general mental speed factor at the apex and broad factors of mental speed forming a second underlying tier" (p. 32). A slightly altered version of McGrew and Evans's (2004) hypothesized hierarchy of speed abilities is formally published here for the first time in Figure 4.5.

More recently, the journal *Psychology in the Schools* published a special issue (Newton &

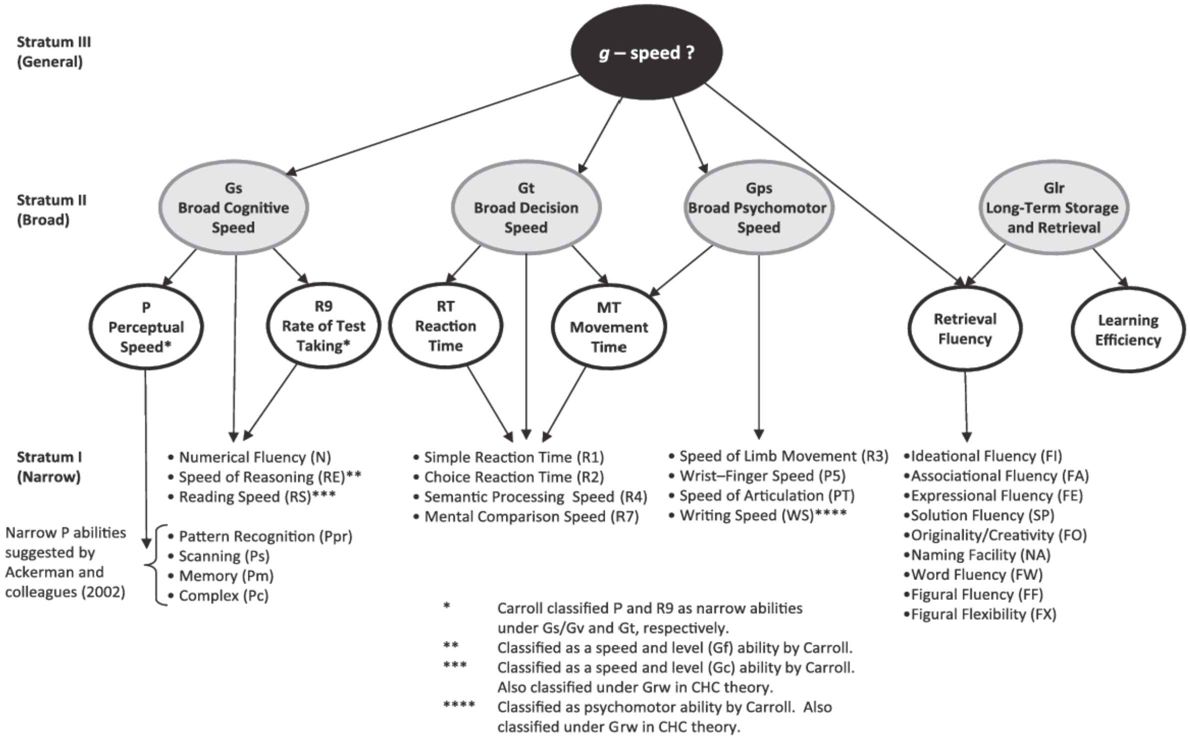

FIGURE 4.5. McGrew and Evans's (2004) hypothesized speed hierarchy, based on integration of Carroll's (1993) speed abilities with other research (Ackerman, Beier, & Boyle, 2002; O'Connor & Burns, 2003; McGrew & Woodcock, 2001; Roberts & Stankov, 1999; Stankov, 2000; Stankov & Roberts, 1997).

McGrew, 2010) that examined the contribution of the contemporary CHC theory in the applied fields of school psychology and special education. The core aim of the special issue was to "take stock" of the 20 years of CHC research jump-started by the 1989 publication of the WJ-R (see Figure 4.1). As articulated by the issue's editors (Newton & McGrew, 2010), the core question addressed was this: "Has the drawing of a reasonably circumscribed 'holy grail' taxonomy of cognitive abilities led to the promised land of intelligence testing in the schools—using the results of cognitive assessments to better the education of children with special needs?" (p. 631). Two broad overview articles were the central focus of the special issue.

Keith and Reynolds's (2010) article reviewed the factor-analytic research on seven different intelligence batteries from the perspective of the CHC model. Keith and Reynolds noted that most new and revised intelligence batteries were either grounded explicitly in CHC theory, or paid some form of implied "allegiance to the theory" (p. 635). Keith and Reynolds (2010) concluded that "although most new and revised tests of intelligence are based, at least in part, on CHC theory, earlier versions generally were not. Our review suggests that whether or not they were based on CHC theory, the factors derived from both new and previous versions of most tests are well explained by the theory" (p. 635).

McGrew and Wendling's (2010) research synthesis in the special issue was designed to answer the question "What have we learned from 20 years of CHC COG–ACH [cognitive–achievement] relations research?" (p. 651). This review produced a number of important conclusions. First, cognitive abilities contribute to academic achievement in different proportions in different academic domains, and these proportions change over the course of development. For example, phonetic coding is relatively unimportant in the domain of mathematics, but is a major influence on the development of reading decoding. However, its influence changes over time. It is quite important in the first few years of schooling but its influence wanes in later childhood.

A second conclusion of McGrew and Wendling's review was that the most consistently salient CHC cognitive–achievement relations exist for narrow (stratum I) cognitive abilities. The authors recommended a refocusing of CHC school-based assessment on selective, referral-focused cognitive assessment of narrow cognitive and achievement abilities. Finally, McGrew and Wendling concluded that the developmentally nuanced relations between primarily narrow cognitive and achievement abilities argue "for more judicious, flexible, selective, 'intelligent' (Kaufman, 1979) intelligence testing where practitioners select sets of tests most relevant to each academic referral. Unless there is a need for a full-scale IQ *g* score for diagnosis (e.g., [intellectual disability], gifted[ness]), professionals need to break the habit of 'one complete battery fits all' testing" (p. 669).

In conclusion, a review of the extant intelligence theory and assessment literature published during the past 20+ years indicates that CHC theory has attained the status as the consensus psychometric model of the structure of human cognitive abilities. We are not alone in our conclusion. Ackerman and Lohman (2006) concluded that "the Cattell–Horn–Carroll (CHC) theory of cognitive abilities is the best validated model of human cognitive abilities" (p. 140).

Kaufman (2009) stated that CHC theory has formed the foundation for most contemporary IQ tests" (p. 91). Keith and Reynolds (2010) concluded that "we believe that CHC theory offers the best current description of the structure of human intelligence" (p. 642). Similarly, Detterman (2011) concluded that

> because the Carroll model is largely consistent with the model originally proposed by Cattell (1971), McGrew (2009) has proposed an integration of the two models which he calls the Cattell–Horn–Carroll (C-H-C) integration model. . . . Because of the inclusiveness of this model, it is becoming the standard typology for human ability. It is certainly the culmination of exploratory factor analysis. (p. 288)

Clearly, the CHC tipping point was reached during the past decade.

Beyond CHC Theory: The Next Generation?

A clear indication of the prominent stature achieved by the CHC theory of intelligence is the fact that it has increasingly been recognized and infused into related psychological assessment arenas and research on intelligence and psychometrics.

CHC-Based Neuropsychological Assessment

The most active CHC "spillover" has been in the area of neuropsychological assessment. A number of CHC-based neuropsychological assessment texts have been published, starting with Hale and Fiorello's *School Neuropsychology: A Practitioner's Handbook* (2004). Two texts by Miller, both with a school neuropsychology focus, are *Essentials of School Neuropsychology* (2007) and *Best Practices in School Neuropsychology: Guidelines for Effective Practice, Assessment, and Evidence-Based Intervention* (2010). It is our opinion that CHC-based neuropsychological assessment holds great potential. Much clinical lore within the field of neuropsychological assessment is tied to specific tests from specific batteries. CHC theory has the potential to help neuropsychologists generalize their interpretations beyond specific test batteries and give them greater theoretical unity.

However, many more CHC-organized factor-analytic studies of joint neuropsychological and CHC-validated batteries are needed before such a synthesis is possible (e.g., see Floyd, Bergeron, Hamilton, & Parra, 2010, and Hoelzle, 2008). Even more crucial are studies that describe the functioning of the brain (e.g., with functional magnetic resonance imaging) during performance on validated tests of CHC abilities.

Finally, it is not yet clear that the variations of ability observed in nondisabled populations are similar to the variations of ability observed in brain-injured populations. Much work needs to be done to verify that when brain injuries occur, CHC ability constructs provide a good framework to describe the kinds of symptoms and losses in function typically observed. If not, CHC theory must be revised or expanded before it can be the primary lens through which neuropsychologists interpret their findings. The potential of CHC-organized neuropsychological assessment is currently that—a yet-to-be-recognized potentiality.

CHC Theory Extensions and Impact

In McGrew's 2005 version of the current chapter, he stated that "older and lesser-used multivariate statistical procedures, such as multidimensional scaling (MDS), need to be pulled from psychometricians' closets to allow for the simultaneous examination of content (facets), processes, and processing complexity" (p. 172) of CHC measures. This recommendation recognized the value of the faceted hierarchical Berlin intelligence structure model (Beauducel, Brocke, & Liepmann, 2001; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002) as a promising lens through which to view CHC theory. Only a select few researchers have heeded this call, although Snow and colleagues (Marshalek, Lohman, & Snow, 1983; Snow, Kyllonen, & Marshalek, 1984) had clearly demonstrated the potential contribution of Guttman's (1954) MDS approach as early as the 1980s. Recent demonstrations of the "added value" that can occur when EFA/CFA intelligence test research is augmented by MDS analyses of the same data include the Cohen, Fiorello, and Farley (2006) three-dimensional (3-D) analysis and interpretation of the Wechsler Intelligence Scale for Children—Fourth Edition (WISC-IV); Tucker-Drob and Salthouse's (2009) MDS analysis of cognitive and neuropsychological test data aggregated across 38 separate studies (*N* = 8,813); and a series of unpublished 2-D and 3-D MDS analyses (and cluster analyses) of the Woodcock–Johnson III (WJ III) norm data, the Wechsler Adult Intelligence Scale—Fourth Edition (WAIS-IV) test correlations, and cross-battery datasets including the WJ III and WISC-R (Phelps, McGrew, Knopik, & Ford, 2005) and WJ III, WAIS-III, Wechsler Memory Scale—Third Edition (WMS-III), and Kaufman Adolescent and Adult Intelligence Test (KAIT) (McGrew, Woodcock, & Ford, 2002) by McGrew. When MDS methods are applied to data previously analyzed with structural EFA/CFA methods, new insights into the characteristics of tests and constructs previously obscured by the strong statistical machinery of factor analysis emerge (Süß & Beauducel, 2005; Tucker-Drob & Salthouse, 2009).

For example, McGrew (2010) has recently presented a multidimensional conceptual cognitive abilities framework based on the integration of (1) the extant CHC research literature, (2) mapping of CHC constructs to neuropsychological constructs and models, (3) results from his MDS-based analyses listed above, and (4) select theoretical constructs from cognitive neurosciences and cognitive information-processing theories.[10] The 16-domain CHC model presented by McGrew (2009) (defined in the second half of this chapter) is embedded in an *ability domain dimension* (along with, and mapped to, neuropsychological assessment domains) that includes (1) cognitive knowledge systems (Gc, Grw, Gq, Gkn); (2) cognitive operations (Gf, Glr, Gv, Ga); (3) cognitive efficiency (Gsm, Gs) and cognitive control (executive functions, including controlled executive attention); (4) sensory functions (visual, auditory, tactile, kinesthetic, olfactory); and (5) motor functions (Gp, Gps). The contribution of cognitive neurosciences is incorporated in this ability domain dimension via the subcategorization of human abilities as type 1 (more automatic cognitive processing) and type II (more deliberate and controlled cognitive processing that is likely to place heavy demands on complex working memory) (see Evans, 2008). The MDS faceted insights into measures of intelligence, largely ignored by most proponents and users of CHC theory, are reflected in a *content/stimulus dimension* of the model, which includes (1) language or auditory–verbal, (2) quantitative or numerical, (3) visual–figural, (4) somatosensory, and (5) olfactory stimulus characteristics of tests of abilities. The *cognitive complexity dimension* incorporates the similar, yet complementary, characterization of cognitive abilities and tests in terms of degree of *cognitive complexity* as elucidated by tests' (or abilities') relative loading on psychometric *g* and nearness in proximity to the center of MDS radex models. The cognitive complexity dimension also indirectly represents the dimension of *breadth of ability domains* (general, broad, narrow).

The brief description of McGrew's multidimensional cognitive abilities framework is offered here in the spirit of positive skepticism articulated in Carroll's (1998) own critique of his 1993 seminal treatise and Jensen's (2004) sage advice that "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" (p. 5). The importance of avoiding a premature "hardening" of the CHC categories has been demonstrated vis-à-vis the structural research on the domain of cognitive mental speed (see Figure 4.5), which suggests a domain characterized by a complex hierarchical structure with a possible *g*-speed factor at the same stratum level as psychometric *g*. The seductive powers of a neat and hierarchically organized CHC structural diagram of cognitive abilities must be resisted. Any theory that is derived primarily from a "rectilinear system of factors is . . . not of a form that well describes natural phenomena" (Horn & Noll, 1997, p. 84). By extension, assessment professionals must humbly recognize the inherent artificial nature of assessment tools built upon linear mathematical models.

Clearly, "intelligence is important, intelligence is complex" (Keith, 1994, p. 209). The current CHC taxonomy has benefited from over 100 years of research by a diverse set of scholars. Yet it is only a temporary "placeholder" taxonomy that is evolving through new research and theorizing, only a small part of which has been described above. Additional (r)evolutions in the constantly evolving taxonomy of human cognitive abilities are presented in the next section of this chapter.

CHC THEORY DESCRIBED AND REVISED

The "Human Cognitive Abilities" conference was held at the University of Virginia in 1994 to honor and discuss Carroll's (1993) masterwork. Cattell, Horn, Carroll, and many other luminaries in the field were in attendance. Published several years later, Carroll's address was called "Human Cognitive Abilities: A Critique" (Carroll, 1998). After reviewing some of the positive reviews of his book (and a few negative ones), he stated,

> Although all these reviews were in one sense gratifying, in another sense they were disappointing. They didn't tell me what I wanted to know: What was wrong with my book and its ideas, or at least what might be controversial about it? . . . Thus, ever since these reviews came out, I've been brooding about their authors might have said but didn't. (p. 6)

The critique of his own theory that followed this statement was a tour de force. Carroll possessed an extraordinarily rare combination of self-confidence, competence, and egoless commitment to truth!

We believe that Carroll's (1993) work is fundamentally sound, and that its major conclusions are as close to correct as current data allow. However, a number of minor inconsistencies in his model deserve some attention. We hope that he would have been gratified by our attempts to critique and improve upon his initial model.

In the sections that follow, we have multiple aims. First, we hope to define each of the constructs in CHC theory in terms that clinicians will find useful. Second, we hope to give some guidance as to which constructs are more central to the theory or have more validity data available. Third, we wish to alert readers to existing controversies and raise some questions of our own. Fourth, we propose a number of additions, deletions, and rearrangements in the list of CHC theory abilities.

We have organized the broad abilities in a way that draws on distinctions made by Cattell's (1971, 1987) triadic theory, Ackerman's (1996) process–personality–interests–knowledge (PPIK) theory, Woodcock's (1993) Gf-Gc information-processing theory, and Horn's (1985) remodeled Gf-Gc theory. There are numerous other valid ways in which this could have been accomplished.

General Intelligence (*g*)

At the apex of most models of CHC theory is the broadest of all cognitive ability constructs—general intelligence (*g*). Cattell, Horn, and Carroll each had different ideas about the origins and existence of psychometric *g*. Cattell (1963) explained the presence of the *g* factor via investment theory (see Figure 4.3 and related text). Carroll (1991) believed that the positive manifold is caused by general intelligence, a unitary construct. Horn (1985) believed there was sufficient evidence to reject the idea of *g*, but did not have strong opinions about any particular explanation of the positive manifold. CHC theory incorporates Carroll's (1993) notion of *g*, but users are encouraged to ignore it if they do not believe that theoretical *g* has merit, particularly in applied clinical assessment contexts.

Domain-Free General Capacities

Some CHC factors (Gf, Gsm, Glr, Gs, and Gt) are not associated with specific sensory systems. These diverse factors may reflect, respectively, different parameters of brain functioning that are relevant in most or all regions of the brain (Cattell, 1987). The fact that they are grouped together does not mean that clinicians should create composite scores with names like "Domain-Free General Capacity" because this is a conceptual grouping, not an implied functional unity.

Fluid Reasoning (Gf)

Definition of Gf

Fluid reasoning (Gf) can be defined as the deliberate but flexible control of attention to solve novel, "on-the-spot" problems that cannot be performed by relying exclusively on previously learned habits, schemas, and scripts. It is a multidimensional construct, but its parts are unified in their purpose: solving unfamiliar problems. Fluid reasoning is most evident in abstract reasoning that depends less on prior learning.[11] However, it is also present in day-to-day problem solving (Sternberg & Kalmar, 1998). Fluid reasoning is typically employed in concert with background knowledge and automatized responses (Goode & Beckman, 2010). That is, such reasoning is employed, even if for the briefest of moments, whenever current habits, scripts, and schemas are insufficient to meet the demands of a new situation. Fluid reasoning is also evident in inferential reasoning, concept formation, classification of unfamiliar stimuli, generalization of old solutions to new problems and contexts, hypothesis generation and confirmation, identification of relevant similarities, differences, and relationship among diverse objects and ideas, the perception of relevant consequences of newly acquired knowledge, and extrapolation of reasonable estimates in ambiguous situations.

Well-Supported Narrow Abilities within Gf

1. *Induction (I): The ability to observe a phenomenon and discover the underlying principles or rules that determine its behavior.* People good at inductive reasoning perceive regularities and patterns in situations that otherwise might seem unpredictable. In most inductive reasoning tests, stimuli are arranged according to a principle and the examinee demonstrates that the principle is understood (e.g., generating a new stimulus that also obeys the principle, identifying stimuli that do not conform to the pattern, or explaining the principle explicitly).

2. *General sequential reasoning (RG): The ability to reason logically, using known premises and principles.* This ability is also known as *deductive reasoning* or *rule application*. Whereas induction is the ability to use known facts to discover new principles, general sequential reasoning is the ability to use known or given principles in one or more logical steps to discover new facts or solve problems. A real-world example would be a judge or jury deciding, given presented facts and relevant laws, if the laws had been violated by certain actions in criminal cases.

3. *Quantitative reasoning (RQ): The ability to reason, either with induction or deduction, with numbers, mathematical relations, and operators.* Tests measuring quantitative reasoning do not require advanced knowledge of mathematics. The computation in such tests is typically quite simple. What makes them difficult is the complexity of reasoning required to solve the problems—for example, "Choose from among these symbols: + – × ÷ = and insert them into the boxes to create a valid equation: 8☐4☐4☐8☐2."

Assessment Recommendations for Gf[12]

Certain narrow abilities are more central to the broad factors than are others. Induction is probably the core aspect of Gf. No measurement of Gf is complete, or even adequate, without a measure of induction. If two Gf tests are given, the second should typically be a General Sequential (Deductive) Reasoning test. A Quantitative Reasoning test would be a lower priority unless there is a specific referral concern about mathematics difficulties or other clinical factors warranting such a focus.

Comments and Unresolved Issues Related to Gf

- *Are Piagetian reasoning (RP) and reasoning speed (RE) distinct aspects of Gf?* Carroll (1997) tendered the tentative hypotheses that reasoning speed and the kinds of tasks used to test Piagetian theories of cognitive development formed distinct narrow factors within Gf. There is little in the way of new evidence that these are distinct factors, and there is some evidence that they are not (Carroll, Kohlberg & DeVries, 1984; Danthiir, Wilhelm, & Schacht, 2005; Inman & Secrest, 1981). For these and other reasons too complicated to describe succinctly here, we have chosen to deemphasize these factors in the current description of CHC theory.

- *Are Gf and g identical?* Gf and *g* are sometimes reported to be perfectly correlated (e.g., Floyd, Evans, & McGrew, 2003; Gustafsson, 1984). Perhaps they are the same construct, although this hypothesis is the subject of considerable debate (see Ackerman, Beier, & Boyle, 2005; Kane, Hambrick, & Conway, 2005). Horn and Blankson (Chapter 3, this volume) note that Gf is theoretically congruent with Spearman's description of *g*. Carroll (2003) believed that there was sufficient evidence to reject the hypothesis that *g* and Gf are identical. Cattell's explanation for why *g* and Gf are so similar is that *g* is really the cumulative effects of a person's Gf from birth to the present ("this year's crystallized ability level is a function of last year's fluid ability level"; Cattell, 1987, p. 139). For this reason, his name for *g* was historical fluid intelligence, or $g_{f(h)}$.

Memory: General Considerations

From reading just the labels of memory abilities, it would appear that there is considerable disagreement among Cattell, Horn, and Carroll. Indeed, at first glance, it also appears that in the domain of memory, CHC theory does not even agree with its source theorists! Fortunately, almost all of the "disagreements" are resolved by the knowledge that the three source theorists sometimes used the same words differently (e.g., *short term*) or used different words to mean the same thing. A close reading of all the major works of CHC's source theorists will reveal that the differences are more apparent than real. The points of agreement are these:

1. It is important to distinguish between long-term memory and short-term memory, but it should not be forgotten that the two systems are interdependent. It is almost impossible to measure (with a single test) short-term memory without involving long-term memory, or to measure long-term memory without involving short-term memory.
2. It is important to distinguish between the ability to recall information stored in long-term memory and the fluency with which this information is recalled. That is, people who learn efficiently may not be very fluent in their recall of what they have learned. Likewise, people who are very fluent in producing ideas from their long-term memory may be slow learners. That is, learning efficiency and retrieval fluency are reasonably distinct abilities.

The scientific literature on memory is truly gigantic, and space does not permit us even to summarize all the topics in this body of research we think are relevant to CHC theory. We expect that this aspect of CHC theory will undergo continual refinement as researchers integrate basic research on memory processes with clinical applications of memory assessment. For now, we articulate a very basic model of how memory may work, so that different aspects of memory assessment can be understood more clearly. We use the terms *primary memory* and *secondary memory* here to avoid confusion that might arise by using analogous terms, such as *short-term memory* and *long-term memory*. Our discussion draws heavily from Unsworth and Engle (2007b).

Primary memory and secondary memory are not individual-difference variables. They are descriptive terms that refer to cognitive structures that everyone has. *Primary memory* refers to information that is in the current focus of attention (i.e., it is immediately accessible to consciousness). *Secondary memory* (also known as *long-term memory*) refers to memory that is not immediately accessible to consciousness. Information enters primary memory via sensory registers or is retrieved from secondary memory.

We will omit a discussion of how the properties of visual primary memory (also known as the *visuospatial sketchpad*) differ from those of auditory primary memory (also known as the *phonological loop*; Baddeley, 1986). What they have in common is a very limited capacity. For example, auditory primary memory holds about four chunks of information in the best of circumstances, and only one or two chunks in typical circumstances. If information is not maintained via rehearsal, it disappears from primary memory within seconds (although it can linger up to 30 seconds or more if no new information displaces it). If attention shifts, the information disappears from primary memory quite quickly. Although information in primary memory is fragile, it is very quickly manipulated and processed (much like RAM in a computer).

To be used (at least consciously), information stored in secondary memory must be retrieved back into primary memory. Some memories are more easily retrieved than others because they have been recently activated, they are more frequently activated, and they are associated with other memories to a greater degree. That is, memories that are unrelated to other memories are difficult to recall. Memories that are overly similar and indistinct (e.g., a string of random numbers) are very difficult to recall.

If primary memory holds only a few chunks of information, how is it that people can repeat back up to seven or more digits on a digits-forward memory span test? To answer this question, we must discuss one of the oldest findings in memory research: the serial position effect. The *serial position effect* consists of two effects, the primacy effect and the recency effect. The *primacy effect* refers to the fact that people are more likely to recall the first few parts of a list than the middle of the list. The typical explanation for this effect is that the first few items on a list are more likely to enter secondary memory. The *recency effect* refers to the tendency that the last two or three items on a list are more likely to be recalled than the middle part of the list.

On the easy items in a digits-forward memory span test, people are able to answer correctly by simply dumping the contents of primary memory. As they approach the limits of primary memory capacity, they begin mentally rehearsing the digits as they are being presented by the examiner. Rehearsal maintains information in primary memory, but also facilitates transfer of information into secondary memory. Most evidence suggests that as people approach their limits of performance on memory span tests, most of the information is pulled from recently activated items in secondary memory, not from primary memory (Unsworth & Engle, 2007a). Why? Because recalling the first part of this list actually displaces the contents of primary memory. If the string of digits is not mostly in secondary memory, the end of the string of digits will not be recalled correctly.

If examinees are allowed to recall any part of a list in any order, many people will adopt the strategy of saying the last few words of the list first and then saying the first part of the list. Thus they are using both primary and secondary memory optimally. This is the most likely reason that Carroll (1993) found evidence for a free-recall factor of memory. Performance on such tests reflects the combined use of primary and secondary memory to a greater degree than memory span tests. In addition, the single-exposure free-recall paradigm requires no memory of sequence, as does the forward memory span paradigm.

It should be noted that Carroll's (1993) free-recall factor was defined by tests in which there was only a single exposure to the list. This is also true of all of Horn's (1985) short-term memory abilities (e.g., associative memory and meaningful memory). These factors were defined mostly by *supraspan* tests (in which the lists to be recalled are longer than most people can recall after a single exposure), and people were given only one learning trial. Because most clinical tests of memory allow multiple learning trials, McGrew (1997) classified such tests as long-term memory tests. Thus neither theorist was wrong about the proper location of these factors. Different task demands alter the relative mix of short- and long-term memory abilities involved in a task. We clarify this confusing aspect of CHC theory for the first time here. In Figure 4.6, we present a conceptual map of the domain of memory in CHC theory.

Short-Term Memory (Gsm)

Definition of Gsm

Short-term memory (Gsm) can be defined as *the ability to encode, maintain, and manipulate information in one's immediate awareness.* Gsm[13] refers to

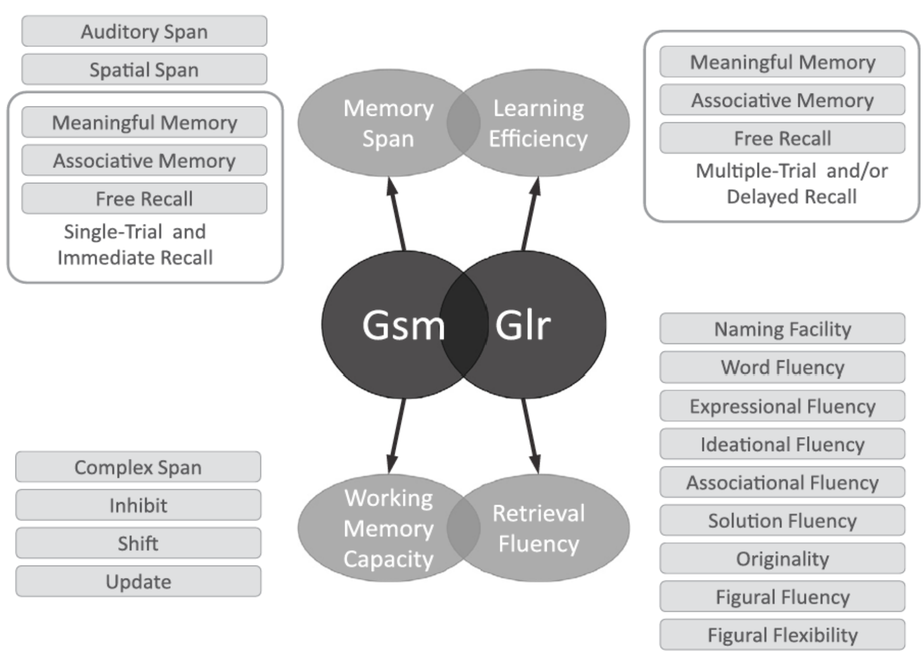

FIGURE 4.6. Conceptual map of memory-related abilities in CHC theory.

individual differences in both the capacity (size) of primary memory and to the efficiency of attentional control mechanisms that manipulate information within primary memory.

Well-Supported Narrow Abilities within Gsm

1. *Memory span (MS): The ability to encode information, maintain it in primary memory, and immediately reproduce the information in the same sequence in which it was represented.* Memory span tests are among the most commonly given tests in both research and clinical settings. In short items, performance is mostly determined by the capacity of primary memory. Participants simply dump the contents of primary memory. For most people, when the item length exceeds three or four, they deliberately engage their attention to maintain information in primary memory (e.g., they subvocally rehearse the list). As the maintenance-only strategy begins to fail, their attention is also directed to searching the contents of recently activated (i.e., just seconds ago) contents of secondary memory. For the most difficult items, there is little that distinguishes simple memory span tests from complex span tests that more directly measure the efficiency of attentional control mechanisms (Unsworth & Engle, 2007a). However, in clinical tests, the whole score represents a mix of several memory processes that are sometimes difficult to tease apart.

One way to get a purer measure of primary memory capacity is to give a test that minimizes the use of strategy (i.e., use of attentional control mechanisms to enhance performance). For example, the Comprehensive Test of Phonological Processing (CTOPP) Memory for Digits subtest presents two digits per second instead of the traditional rate of one digit per second. People who take both types of tests sometimes express surprise that the test with the faster rate was somehow easier than the memory span test with the slower rate. What they mean is that they just pulled information from primary memory (and a little bit from secondary memory) because they were simply unable to use attention-demanding strategies for maintaining information in primary memory or storing information in secondary memory.

It appears that auditory and visual (spatial) memory span tests draw on different abilities (Kane et al., 2004). We suspect that the two types of tests reflect the efficiency of Ga and Gv, respectively, in encoding the test stimuli. When the test stimuli become difficult to encode, visual memory tests load with Gv (such tests define Visual Memory, a narrow ability associated with Gv) and auditory memory tests load with Ga (e.g., the CTOPP Nonword Repetition subtest, in which examinees must repeat increasingly long nonsense words such as *haviormushkimelour*). However, when visual and auditory tests demand more attentional resources, the auditory–visual distinction becomes unimportant (Kane et al., 2004).

2. *Working memory capacity:*[14] *The ability to direct the focus of attention to perform relatively simple manipulations, combinations, and transformations of information within primary memory, while avoiding distracting stimuli and engaging in strategic/controlled searches for information in secondary memory.* These attentional control mechanisms are mostly under direct conscious control and are thus known by various terms containing the word *executive* (e.g., executive attention, executive control, central executive, executive functions, and many more). In this context, *executive* means that which *executes* (initiates, performs, controls) an action. Evidence that so-called "working memory capacity" tests and "executive function" tests belong in the same conceptual category is that a recent study rigorously designed to distinguish between the two constructs found that they were nearly perfectly correlated (r = .97) at the latent-variable level (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010).

Working memory capacity tests are typically measured by tasks in which information must be encoded (stored) and transformed (processed). The processing demands of these tasks is usually sufficient to bump information continuously out of primary memory. Thus successful performance on these tasks depends on efficient transfer of information to secondary memory and efficient retrieval of that information when it is needed (hence Horn's term *short-term apprehension and retrieval*). Most working memory capacity tests used in research are called "complex span" tests. Typically, participants must process information (e.g., verify whether a statement is true or false) and remember information (e.g., the last word in a sentence). The only clinical test that uses the complex span paradigm is the latter half of the Stanford–Binet Intelligence Scales, Fifth Edition (SB5) Verbal Working Memory subtest. However, many other clinical tests require encoding and attention-demanding processing of stimuli, such as the WISC-IV Letter–Number Sequencing subtest (among many others).

A number of attempts have been made to distinguish among various aspects of executive attentional control. One influential study distinguished between three functions: updating the contents of short-term memory, shifting of attention, and inhibition of responses/urges that are typically strongly cued by particular stimuli (Miyake et al., 2000). All three of these functions have to do with directing one's attention in the service of a goal, even when it is difficult to do so.

Assessment Recommendations for Gsm

We recommend using auditory Gsm tests for most purposes because most of the research showing relationships between Gsm and academic functioning have used auditory tests. We recommend using simple memory span tests and attention-demanding short-term memory tests to distinguish between short-term memory capacity problems and problems of executive attentional control.

Comments and Unresolved Issues Related to Gsm

- *Is Gsm g or Gf?* One important study suggested that Gf could be almost entirely explained by working memory capacity tests (Kyllonen & Christal, 1990). Replications using more refined methods have found that although the relationship between working memory capacity and Gf is substantial, the constructs are distinct (Unsworth & Engle, 2007b). It appears that adequate attentional resources are necessary for novel reasoning, but are not sufficient to explain entirely why some people are better than others at Gf tests.

- *Should Gsm be renamed?* Labels matter. A poorly named ability construct can cause misinterpretations, misdiagnoses, and therapeutic missteps—witness the confusion caused by naming one of the WISC-III's factor index scores "Freedom from Distractibility" (Kaufman, 1994, p. 212). Thankfully, this problem was resolved when the factor was renamed "Working Memory" on the WISC-IV. However, this new label highlights an ambiguity in the field of cognitive assessment. Many of us use the term *working memory capacity* to refer to the superordinate category of Gsm, whereas others use it to refer to a narrow ability within Gsm. For this reason, we considered eliminating this ambiguity from CHC theory by avoiding the term *working memory* altogether. The plan was to leave the name of Gsm unchanged, and to change the name of the narrow CHC ability construct *working memory* to *attentional control*. There are many attractive features of this label, but like "freedom from distractibility," we believe that it would be likely to be misinterpreted, particularly in the context of diagnostic decisions related to ADHD. Although it is true that people with ADHD perform somewhat worse on measures of working memory capacity, the cognitive deficits associated with that disorder are more diverse than what is meant by attentional control (Barkley, 1997). Multidimensional constructs like attention are practically impossible to operationalize with a single type of test. Indeed, clinical measures of working memory capacity are merely a subset of a very diverse set of clinical measures of attention-related abilities. We worried that had we called the narrow ability "attentional control," that its meaning would be misinterpreted and it would be treated as if it represented "attention" in its totality. For all its faults, the term *working memory capacity* is so firmly established that it is likely to remain with us for quite some time. Even so, it is important to keep in mind that working memory capacity is not strictly a phenomenon of memory alone. By analogy, tests of working memory capacity are a bit like hurdling. Hurdling is the smooth alternation of running and jumping. However, there are many other kinds of running, and many other kinds of jumping than the kinds seen in hurdling events. Likewise, tests of working memory capacity involve the use of memory and attention in concert, but there are many other kinds of memory and many other kinds of attention than the kinds seen in these tests.

Long-Term Storage and Retrieval (Glr)

Definition of Glr

Long-term storage and retrieval (Glr) can be defined as *the ability to store, consolidate, and retrieve information over periods of time measured in minutes, hours, days, and years.* Short-term memory has to do with information that has been encoded seconds ago and must be retrieved immediately. What distinguishes Gsm tests from Glr tests is that in Gsm tests there is a continuous attempt to maintain awareness of that information. A Glr test involves information that has been put out of immediate awareness long enough for the contents of primary memory to be displaced completely. In Glr tests, continuous maintenance of information in primary memory is difficult, if not impossible.

Glr is distinguished from Gc and other acquired-knowledge factors in that Glr refers to the processes of memory (storage/learning efficiency and retrieval fluency), and Gc (and other acquired-knowledge factors) refers to the breadth of information stored in long-term memory. Presumably, people with high Gc acquired knowledge via Glr processes, but it is possible for highly motivated people to acquire quite a bit of knowledge even if their learning processes are inefficient.

There is a major division within Glr that was always implied in CHC theory, but we are making it more explicit here. Some Glr tests require efficient learning of new information, whereas others require fluent recall of information already in long-term memory.

Well-Supported Narrow Abilities within Glr

Glr LEARNING EFFICIENCY

Carroll (1993) noted that there was some evidence for learning abilities (his abbreviation for this ability was L1) but it was incomplete. We believe that factor analyses of the WJ III, WAIS-IV/WMS-IV, Kaufman Assessment Battery for Children—Second Edition (KABC-II), and other clinical batteries with learning tests now provide sufficient evidence that long-term learning is distinct from fluency on the one hand and from Gsm on the other. As noted previously, many memory test paradigms (paired associates, story recall, list learning) can be administered with only one exposure to the information to be learned. In such cases, they are measuring aspects of Gsm. If the tests require delayed recall or if they use multiple exposures to learn information, they are measures of Glr.

All tests of learning efficiency must present more information than can be retained in Gsm. This can be accomplished with the *repeated-supraspan* paradigm, in which evaluees are asked to remember more information than they can learn in one exposure and then the information is presented several more times. An example of this type of task is the Wide Range Assessment of Memory and Learning, Second Edition (WRAML2) Verbal Learning subtest, a free-recall list-learning test. This method is somewhat messy because part of the performance involves Gsm to a significant degree. A paradigm that minimizes the involvement of Gsm is the *structured learning task*. Such tasks have a teach–test–correct structure. First, a single bit of information is taught. That item is tested, and corrective feedback is offered if required. Another item is taught, and both items are tested with corrective feedback if needed. Then another item is taught, and all three items are tested with corrective feedback if needed. Thus the test becomes longer and longer, but short-term memory is never overwhelmed with information. The WJ III Visual–Auditory Learning subtest is a good example of a structured learning task.

1. *Associative memory (MA): The ability to remember previously unrelated information as having been paired*. Pairs of items are presented together in the teaching phase of the test. In the testing phase, one item of the pair is presented, and the examinee recalls its mate. Item pairs must not have any previously established relationships (e.g., the word pairs *table–chair, woman–girl*), or the test is also a measure of meaningful memory.

2. *Meaningful memory (MM): The ability to remember narratives and other forms of semantically related information*. Carroll (1993) allowed for tests of meaningful memory to have a variety of formats (e.g., remembering definitions to unfamiliar words), but the core of this ability is the ability to remember the gist of a narrative. After hearing a story just once, most people can retell the gist of it fairly accurately. People who cannot do so are at a severe disadvantage in many domains of functioning. Stories are how we communicate values, transmit advice, and encapsulate especially difficult ideas. Much of the content of our interpersonal relationships consists of the stories we tell each other and the shared narratives we construct. Indeed, much of our sense of identity is the story we tell about ourselves (McAdams, Josselson, & Lieblich, 2006).

Many so-called "story recall" tests are barely concealed lists of disconnected information (e.g., "Mrs. Smith and Mr. Garcia met on the corner of Mulberry Street and Vine, where they talked about the weather, their favorite sports teams, and current events. Mr. Garcia left to buy gum, shoelaces, and paperclips. Mrs. Smith left to visit with her friends Karen, Michael, and Susan . . . "). A good story recall test has a story that has a true narrative arc. Because stories rely on conventions and require the listener to understand certain conventions of language and culture, many story memory tests have a strong secondary loading on Gc.

3. *Free-recall memory (M6): The ability to recall lists in any order*. Typically, this ability is measured by having evaluees repeatedly recall lists of

10–20 words. What distinguishes this ability from a method factor is that free-recall tests allow the evaluee to strategically maximize the primacy and recency effect by dumping the contents of primary memory first.

Glr RETRIEVAL FLUENCY

People differ in the rate at which they can access information stored in long-term memory. This aspect of ability has become increasingly recognized as important because of its role in reading comprehension. There is also a long-standing line of research showing that fluency of recall is an important precursor to certain forms of creativity. People who can produce many ideas from memory quickly are in a good position to combine them in creative ways. That said, high retrieval fluency is only a facilitator of creativity, not creativity itself.

The fluency factors in the following group are alike in that they involve the production of ideas.

4. *Ideational fluency (FI): The ability to rapidly produce a series of ideas, words, or phrases related to a specific condition or object.* Quantity, not quality or response originality, is emphasized. An example of such a test would be to think of as many uses of a pencil as possible in 1 minute.

5. *Associational fluency (FA): The ability to rapidly produce a series of original or useful ideas related to a particular concept.* In contrast to ideational fluency (FI), quality rather than quantity of production is emphasized. Thus the same question about generating ideas about uses of pencils could be used, but credit is given for creativity and high-quality answers.

6. *Expressional fluency (FE): The ability to rapidly think of different ways of expressing an idea.* For example, how many ways can you say that a person is drunk?

7. *Sensitivity to problems/alternative solution fluency (SP): The ability to rapidly think of a number of alternative solutions to a particular practical problem.* For example, how many ways can you think of to get a reluctant child to go to school?

8. *Originality/creativity (FO): The ability to rapidly produce original, clever, and insightful responses (expressions, interpretations) to a given topic, situation, or task.* This factor is quite difficult to measure for a variety of reasons. Because originality manifests itself in different ways for different people, such diversity of talent does not lend itself to standardized measurement. This factor is not strictly a "retrieval" factor because it is by definition a creative enterprise. However, much of creativity is the combination of old elements in new ways. When we say that one idea sparks another, we mean that a person has retrieved a succession of related ideas from memory, and their combination has inspired a new idea.

The next two fluency abilities are related in that both are related to the fluent recall of words.

9. *Naming facility (NA): The ability to rapidly call objects by their names.* In contemporary reading research, this ability is called *rapid automatic naming* (RAN) or speed of lexical access. A fair measure of this ability must include objects that are known to all examinees; otherwise, it is a measure of lexical knowledge. This is the only fluency factor in which each response is controlled by testing stimulus materials. The other fluency factors are measured by tests in which examinees generate their own answers in any order they wish. In J. P. Guilford's terms, this is an ability involving *convergent production*, whereas the other fluency factors involve *divergent production* of ideas. In this regard, naming facility tests have much in common with Gs tests; they are self-paced tests in which an easy task (naming common objects) must be done quickly and fluently in the order determined by the test developer. Deficits in this ability are known to cause reading comprehension problems (in a sense, reading is the act of fluently "naming" printed words; Bowers, Sunseth, & Golden, 1999).

10. *Word fluency (FW): The ability to rapidly produce words that share a nonsemantic feature.* An example of a test that measures this ability is to name as many words as possible that begin with the letter *T*. This has been mentioned as possibly being related to the "tip-of-the-tongue" phenomenon (e.g., word-finding difficulties; Carroll, 1993). This is an ability that is well developed in Scrabble and crossword puzzle fans.

The next two fluency factors are related to figures.

11. *Figural fluency (FF): The ability to rapidly draw or sketch as many things (or elaborations) as possible when presented with a nonmeaningful visual stimulus (e.g., a set of unique visual elements).* Quantity is emphasized over quality. For example, in one part of the Delis–Kaplan Design Fluency test, examinees must connect dots with four straight lines in as many unique ways as they can within a time limit.

12. *Figural flexibility (FX): The ability to rapidly draw different solutions to figural problems.* An example of a test that measures this ability is to draw as many different ways as possible to fit several small shapes into a larger one.

Assessment Recommendations for Glr

We recommend measuring learning efficiency with structured learning tasks to minimize the contaminating effects of Gsm. However, repeated-supraspan tasks do allow a clinician to see how examinees use strategy to learn things. Structured learning tasks usually measure associative memory. We also recommend measuring meaningful memory because of its clear diagnostic value. Of the fluency measures, we recommend a measure of naming facility and a measure of ideational fluency, as the predictive validity of these factors is better understood than for the others.

Comments and Unresolved Issues Related to Glr

- *Is Glr retrieval fluency a distinct factor or a combination of Gs and attentional control?* In factor analyses, Glr retrieval fluency measures regularly load with Gs measures (e.g., in the Differential Ability Scales—Second Edition [DAS-II]) or with attentional control aspects of Gsm. Usually this happens where there are not enough fluency measures or Gs measures in the analysis for the two factors to emerge. When the two constructs are well represented in the correlation matrix, the factors appear as distinct abilities. Even so, it is likely that Gs and Glr share some variance, as both are speeded (see Figure 4.5). Theoretically, the attentional control aspects of Gsm are responsible for searching and retrieving from long-term memory. However, the two concepts appear to be reasonably distinct.

Cognitive Speed: General Considerations

Figure 4.5 displays an overview of how CHC speed abilities are believed to be related. This overview is mostly based on the model proposed by McGrew and Evans (2004), who integrated Carroll's (1993) model with more recent research (Ackerman, Beier, & Boyle, 2002; McGrew & Woodcock, 2001; O'Connor & Burns, 2003; Roberts & Stankov, 1999; Stankov, 2000; Stankov & Roberts, 1997). Both processing speed (Gs) and reaction and decision speed (Gt) are general abilities related to speed. Both have to do with speed on very easy tests, although Gt tests are generally easier than Gs tests. What distinguishes Gs from Gt is fluency. Gt refers to the speed at which a single item can be performed, on average. That is, each item is presented singly, and the examiner controls the pace at which the next item is presented. Gs refers to the average speed at which a series of simple items is done *in succession* with *sustained concentration* over all items. That is, all items are presented at once, and the examinee determines when the next item will be attempted. In Gt tests the quickness of responding each time, with pauses between items, is critical. In Gs tests there are no pauses, and the examinee must sustain mental quickness and move swiftly from item to item until told to stop. This seemingly small difference makes a big difference. In Gs tests, the examinee is constantly shifting attention from item to item. Performance can be enhanced (or hindered) by looking ahead to the next several items. In Gt tests, this is not possible because the examiner determines when the next item is seen. Thus Gt is more purely about speed of perception or quickness of reactions, whereas Gs is more about the combination of sustained speed, fluency, and the adaptive allocation of attention. For this reason, Gs is more strongly correlated with *g* (and Gf) than is Gt.

Processing Speed (Gs)

Definition of Gs

Processing speed (Gs) can be defined as *the ability to perform simple, repetitive cognitive tasks quickly and fluently.* This ability is of secondary importance (compared to Gf and Gc) in predicting performance during the learning phase of skill acquisition. However, it becomes an important predictor of skilled performance once people know how to do a task. That is, once people know how to perform a task, they still differ in the speed and fluency with which they perform (Ackerman, 1987). For example, two people may be equally accurate in their addition skills, but one recalls math facts with ease, whereas the other has to think about the answer for an extra half-second and sometimes counts on his or her fingers.

Well-Supported Narrow Abilities within Gs

1. *Perceptual speed (P): The speed at which visual stimuli can be compared for similarity or difference.* Much as induction is at the core of Gf, perceptual

speed is at the core of Gs. One way to measure this factor is to present pairs of stimuli side by side, and the examinees judge them to be the same or different as quickly as possible. Another method of measuring this factor is to present a stimulus to examinees, and they must find matching stimuli in an array of heterogeneous figures. Research (Ackerman, Beier, & Boyle, 2002; Ackerman & Cianciolo, 2000; see McGrew, 2005) suggests that perceptual speed may be an intermediate-stratum ability (between narrow and broad) defined by four narrow subabilities: (a) pattern recognition (Ppr), the ability to quickly recognize simple visual patterns; (b) scanning (Ps), the ability to scan, compare, and look up visual stimuli; (c) memory (Pm), the ability to perform visual-perceptual speed tasks that place significant demands on immediate Gsm; and (d) complex (Pc), the ability to perform visual pattern recognition tasks that impose additional cognitive demands, such as spatial visualization, estimating and interpolating, and heightened memory span loads.

2. *Rate of test-taking (R9): The speed and fluency with which simple cognitive tests are completed.* Carroll's (1993) analyses of this factor included very heterogeneous variables (different contents, different task formats, different degrees of difficulty). Originally, there were no "rate-of-test-taking" tests. Instead, other tests measuring other abilities were given and the finishing times were recorded. It was found that there are individual differences in people's test-taking tempo, regardless of the type of test. Through the lens of CHC theory, the definition of this factor has narrowed to simple tests that do not require visual comparison (so as not to overlap with perceptual speed) or mental arithmetic (so as not to overlap with number facility). For example, the WISC-IV Coding subtest requires examinees to look up numbers in a key and produce an associated figure specified by the key.

The next three factors are related to the ability to perform basic academic skills rapidly.

3. *Number facility (N): The speed at which basic arithmetic operations are performed accurately.* Although this factor includes recall of math facts, number facility includes speeded performance of any simple calculation (e.g., subtracting 3 from a column of two-digit numbers). Number facility does not involve understanding or organizing mathematical problems and is not a major component of mathematical/quantitative reasoning or higher mathematical skills. People with slow recall of math facts may be more likely to make computational errors because the recall of math facts is more effortful (i.e., consumes attentional resources) and is thus a source of distraction.

4. *Reading speed (fluency) (RS): The rate of reading text with full comprehension.* Also listed under Grw.

5. *Writing speed (fluency) (WS): The rate at which words or sentences can be generated or copied.* Also listed under Grw and Gps.

Assessment Recommendations for Gs

We recommend that the assessment of Gs primarily focus on perceptual speed and secondarily on rate of test taking. The three academic fluency factors should be assessed if they are relevant to the referral concern. These abilities sometimes act as predictors of more complex aspects of academic achievement (e.g., reading comprehension and math problem solving) and sometimes are considered academic outcomes themselves, depending on the referral concern. Many evaluees seek extended time on exams, and poor academic fluency is often considered sufficient justification for granting this accommodation.

Comments and Unresolved Issues Related to Gs

- *To what degree do the three academic fluency abilities depend on Glr fluency?* Each of the three academic fluency abilities requires fluent recall of information stored in long-term memory. Recalling math facts seems to be a close twin of naming facility (i.e., if the answer is remembered rather than computed). Once readers automatize reading of simple words (the words are recalled lexically rather than decoded phonetically), it would seem that this is also a special case of naming facility. Further research will clarify the degree to which these tasks call on the same cognitive processes.

Reaction and Decision Speed (Gt)

Definition of Gt

Reaction and decision speed (Gt) can be defined as *the speed of making very simple decisions or judgments when items are presented one at a time.* Tests of Gt differ from tests of Gs in that they are not self-paced. Each item is presented singly and there is a short period between items in which no response from the evaluee is required. The primary use of Gt measures has been in research settings. Researchers are interested in Gt, as it may provide some insight into the nature of *g* and some very basic properties of the brain (e.g., neural efficiency). One of the interesting aspects of Gt is that not only is faster reaction time in these very simple tasks associated with complex reasoning, but so is greater consistency of reaction time (less variability). People with more variable reaction times have lower overall cognitive performance (Jensen, 2006).

Well-Supported Narrow Abilities within Gt

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

2. *Choice reaction time (R2): Reaction time when a very simple choice must be made*. For example, examinees see two buttons and must hit the one that lights up.

3. *Semantic processing speed (R4): Reaction time when a decision requires some very simple encoding and mental manipulation of the stimulus content*.

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

5. *Inspection time (IT): The speed at which differences in stimuli can be perceived*. For example, two lines are shown for a few milliseconds and then are covered up. The examinee must indicate which of the two lines is longer. If given sufficient time, all examinees are able to indicate which is the longer line. The difficulty of the task is determined by how much time the examinees have to perceive the lines. The inspection time paradigm is noteworthy because it does not require a rapid response and thus has no confounds with Gps. Measures of inspection time correlate with the *g* factor at approximately $r = .4$ (Jensen, 2006).

Assessment Recommendations for Gt

Tasks measuring Gt are not typically used in clinical settings (except perhaps in continuous-performance tasks). With the increasing use of low-cost mobile computing devices (smartphones; iPads and other slate notebook computers), we would not be surprised to see viable measures of Gt become available for clinical and applied use.

Psychomotor Speed (Gps)

Definition of Gps

Psychomotor speed (Gps) can be defined as *the speed and fluidity with which physical body movements can be made*. In Ackerman's (1987) model of skill acquisition, Gps is the ability that determines performance differences after a comparable population (e.g., manual laborers in the same factory) has practiced a simple skill for a very long time.

Well-Supported Narrow Abilities within Gps

1. *Speed of limb movement (R3). The speed of arm and leg movement*. This speed is measured after the movement is initiated. Accuracy is not important.

2. *Writing speed (fluency) (WS). The speed at which written words can be copied*. Also listed under Grw and Gps.

3. *Speed of articulation (PT). The ability to rapidly perform successive articulations with the speech musculature*.

4. *Movement time (MT)*. Recent research (see summaries by Deary, 2003; Nettelbeck, 2003; see also McGrew, 2005) suggests that MT may be an intermediate-stratum ability (between narrow and broad strata) that represents the second phase of reaction time as measured by various elementary cognitive tasks (ECTs). The time taken to physically move a body part (e.g., a finger) to make the required response is MT. MT may also measure the speed of finger, limb, or multilimb movements or vocal articulation (*diadochokinesis*; Greek for "successive movements") (Carroll, 1993; Stankov, 2000) and is also listed under Gt.

Assessment Recommendations for Gps

Psychomotor speed is not generally used in clinical settings except for finger-tapping tests in neuropsychological settings. Although the speed of finger tapping is of some interest to neuropsychologists, they are more concerned with performance that is dramatically uneven on the right and left hands, as this may indicate in which hemisphere a brain injury may have occurred.

Acquired Knowledge

The next four abilities, Gc, Gkn, Grw, and Gq, are consistent with Cattell's (1943) original description of g_c. They all involve the acquisition of useful knowledge and understanding of important domains of human functioning. All of these factors represent information stored in long-term memory.

Comprehension–Knowledge (Gc)

Definition of Gc

Comprehension–knowledge (Gc) can be defined as *the depth and breadth of knowledge and skills that are valued by one's culture*. Every culture values certain skills and knowledge over others. For example, Gc-type verbal abilities have been found to be the first of three major factors considered to define intelligence when both experts in the field of intelligence and laypeople are surveyed (Sternberg, Conway, Ketron, & Bernstein, 1981). Gc reflects the degree to which a person has learned practically useful knowledge and mastered valued skills. Thus, by definition, it is impossible to measure Gc independent of culture. Gc is theoretically broader than what is measured by any existing cognitive battery (Keith & Reynolds, 2010).

Ideally, Gc is measured with tests that minimize the involvement of Gf. This means making the tests straightforward and less like puzzles. Gc tests typically do not require intense concentration. Items expected to be known only by experts in a field are avoided (e.g., "What is the difference between Pearson's r and Spearman's ρ?" "Who was William Henry Harrison's Secretary of the Treasury?" "What is the solvent most commonly used by dry cleaners?"). For typical Gc test items, almost anyone who graduates from high school has a reasonable chance of at least being exposed to the information. A good easy Gc item is not merely easy, but should reveal a serious knowledge deficit if not answered correctly. An adult who does not know why milk is stored in a refrigerator is probably not ready to live independently in unsupervised housing.

A good hard item on a Gc test is not merely obscure. It should reflect uncommon wisdom (e.g., "Explain what Voltaire might have meant when he said, 'To be absolutely certain about something, one must know everything or nothing about it' "), or it should be associated with deep knowledge of important aspects of one's local culture. For example, the question "Julius Caesar's nephew Octavian is also known as ____________" may seem trivial at first glance. However, the story of Rome's transition from a republic to an empire has long served as a cautionary tale of what might happen to the U.S. system of government if the citizenry does not vigilantly guard its liberties.

Compared to other cognitive abilities, Gc is relatively more easily influenced by factors such as experience, education, and cultural opportunities, but is also just as heritable as Gf (Horn & Noll, 1997). Gc is historically known as *crystallized intelligence*. Although it is featured prominently in CHC theory, Hunt (2000) has lamented the fact that researchers and intelligence scholars have largely ignored Gc recently in favor of studying more exciting or "sexy" CHC constructs (e.g., Gf). He has called it the "wallflower" ability.

Well-Supported Narrow Abilities within Gc

1. *General verbal information (K0): The breadth and depth of knowledge that one's culture deems essential, practical, or otherwise worthwhile for everyone to know.* This ability is distinguished from achievement tests and other domain-specific tests of specialized knowledge in that it refers to acquired knowledge across many domains. Although any particular item in a general verbal information test might look like an item from a more specialized test, the purpose of a general verbal information test is to measure the cumulative effects of exposure to and retention of diverse forms of culturally relevant information. Items testing general verbal information can require a very simple response (e.g., "Which country was formerly known as Rhodesia?"), or they can require a fairly in-depth explanation (e.g., "What does *comparative advantage* mean in economics?"). What distinguishes the first question from mere trivia is that a person who knows the answer probably also knows why the name of the country changed and has some idea as to why that country is currently so troubled.

2. *Language development (LD): General understanding of spoken language at the level of words, idioms, and sentences.* In the same way that induction is at the core of Gf, language development is at the core of Gc. Although LD is listed as a distinct narrow ability in Carroll's model, his description of his analyses make it clear that he meant language development as an intermediate category between Gc and more specific language-related abilities, such as lexical knowledge, grammatical sensitivity, and listening ability. Language development is separate from general information. It appears to be

a label for all language abilities working together in concert. Language development is an obvious precursor skill for reading comprehension. However, the influence between the two abilities is bidirectional: Children who understand language are able to enjoy reading, and are thereby exposed through print to complex aspects of language that only rarely occur in speech.

3. *Lexical knowledge (VL): Knowledge of the definitions of words and the concepts that underlie them.* Whereas language development is more about understanding words in context, lexical knowledge is more about understanding the definitions of words in isolation. This does not mean that it is a shallow skill, though. For people with deep lexical knowledge, each word in the dictionary is a cognitive aid or tool to help them understand and talk about the world around them. Lexical knowledge is also an obvious precursor skill for reading decoding and reading comprehension. As with language development, people who read more acquire vocabulary words that are more likely to appear in print than in speech.

4. *Listening ability (LS): The ability to understand speech.* This ability is typically contrasted with reading comprehension. Tests of listening ability typically have simple vocabulary, but increasingly complex syntax or increasingly long speech samples to listen to.

5. *Communication ability (CM): The ability to use speech to communicate one's thoughts clearly.* This ability is comparable to listening ability, except that it is productive (expressive) rather than receptive. Carroll's factor came from studies in which people had to communicate their thoughts in nontesting situations (e.g., giving a speech). Although there are many tests in which people are asked to compose essays, we are not aware of language tests in which people are asked to communicate orally in a comparable fashion.

6. *Grammatical sensitivity (MY): Awareness of the formal rules of grammar and morphology of words in speech.* This factor is distinguished from English usage in that it is manifested in oral language instead of written language, and that it measures more the *awareness* of grammar rules than correct usage.

Assessment Recommendations for Gc

Adequate measurement of Gc should include a measure of general information and a test of either language development or lexical knowledge (which is a facet of language development). If there is time to give three Gc tests, a test of listening ability is a good choice.

Comments and Unresolved Issues Related to Gc

- *Is oral production and fluency (OP) distinct from communication ability (CM)?* Carroll (1993) identified a very narrow oral speaking ability called *oral production and fluency*. What distinguished this factor from communication ability was that the former was measured in realistic settings (e.g., giving a speech in front of an audience). Given that the evidence for the OP factor is very weak, this distinction does not seem important enough to clutter up the model, at least until compelling evidence suggests otherwise.
- *Is foreign-language aptitude an ability?* Carroll listed foreign-language aptitude as an ability, but his definition did not match what he meant by stratum I abilities elsewhere. What he seemed to mean by it was the sum total of all the relevant cognitive predictors of success in learning foreign languages, which include grammatical sensitivity, phonetic coding, and lexical knowledge. Aptitudes are not abilities; they are combinations of abilities used to forecast achievement (Corno et al., 2002). For this reason, we have removed this factor from the list of CHC theory abilities. This does not mean that foreign-language aptitude "does not exist." It does exist. It is just a different kind of construct.

Domain-Specific Knowledge (Gkn)

Definition of Gkn

Domain-specific knowledge (Gkn) can be defined as *the depth, breadth, and mastery of specialized knowledge (knowledge not all members of a society are expected to have).* Specialized knowledge is typically acquired via one's career, hobby, or other passionate interests (e.g., religion, sports). Knowledge has been featured in a number of definitions of intelligence, particularly during adulthood. It has been described as a "central ingredient of adult intellect" (Ackerman, 1996, p. 241). Schank and Birnbaum (1994) stated that "The bottom line is that intelligence is a function of knowledge. One may have the potentiality of intelligence, but without knowledge, nothing will become of that intelligence" (p. 102).

The "G" in Gkn is somewhat paradoxical. There is no general ability called "Gkn" because all of the abilities within the Gkn domain are specific by definition. Yet when all possible specific Gkn domains are considered collectively, it is broader than Gc (Hambrick, Pink, Meinz, Pettibone, & Oswald, 2008). Ackerman and colleagues (Ackerman, 1996; Hambrick et al., 2008) have conducted the most systematic study of the domain of Gkn in adults. In addition to the importance of Gc and prior domain knowledge as predictors, these researchers have clearly demonstrated that learning new domain-specific knowledge (particularly declarative knowledge) is also influenced by a number of nonability (conative) variables. These conative variables include situational and individual interest and the Big Five personality characteristics of *openness to experience* and *typical intellectual engagement*. The *need for cognition* personality trait has also been implicated as a causal factor. The Ackerman intelligence-as-process, personality, interest, and intelligence-as-knowledge (PPIK) theory of intelligence is the best available empirically based comprehensive explanation of the development of Gkn abilities (Ackerman, 1996; Hambrick et al., 2008). The PPIK theory has its conceptual roots in Cattell's Investment hypothesis (see Figure 4.3).

Gkn is unusual in that the proper reference group is not a person's same-age peers in the general population. Rather, the basis of comparison for Gkn is a group of people expected to have the same kinds of specialized knowledge. For example, when measuring an oncologist's Gkn in oncology, it only makes sense to compare the oncologist's knowledge with the average score of other oncologists. Gkn is also unusual in that there are an infinite number of possible narrow factors of specialized knowledge (i.e., one for each potential specialization).

In Gc tests, there is a sense in which people are expected to know the answers to all of the test questions. In Gkn tests, there is no such expectation unless the person is a member of a certain profession or is considered an expert in a certain domain. The fact that a nurse does not know how to tune a guitar has no bearing on the evaluation of the nurse's abilities. However, if the nurse does not know how to administer a shot, the nurse would be considered incompetent, as would a guitarist who is unable to tune a guitar.

Another noteworthy distinction between Gc and Gkn is their differing relationships with working memory. When solving problems outside of their expertise, most experts are unable to perform extraordinary feats of working memory. However, in a phenomenon called *expertise wide- span memory* (see Horn & Blankson, Chapter 3, this volume), experts seem to be able to access large amounts of specialized knowledge very quickly in long-term memory, and are able to hold it in immediate awareness as if it were stored in working memory, so that it can be used to solve complex problems efficiently. Thus, instead of being able to hold a few chunks of information in working memory, experts seem to perform as if they are able to hold very large amounts of information in working memory, but only when working within their areas of specialization.

Well-Supported Narrow Abilities within Gkn

1. *Foreign-language proficiency (KL): Similar to language development, but in another language.* This ability is distinguished from foreign-language aptitude in that it represents achieved proficiency instead of potential proficiency. Presumably, most people with high foreign-language proficiency have high foreign-language aptitude, but not all people with high foreign-language aptitude have yet developed proficiency in any foreign languages. This ability was previously classified as an aspect of Gc. However, since Gkn was added to CHC theory, it is clear that specialized knowledge of a particular language should be reclassified. Although knowledge of English as a second language was previously listed as a separate ability in Gkn, it now seems clear that it is a special case of the more general ability of foreign-language proficiency. Note that this factor is unusual because it is not a single factor: There is a different foreign-language proficiency factor for every language.

2. *Knowledge of signing (KF): Knowledge of finger spelling and signing (e.g., American Sign Language).*

3. *Skill in lip reading (LP): Competence in the ability to understand communication from others by watching the movements of their mouths and expressions.*

4. *Geography achievement (A5): Range of geography knowledge (e.g., capitals of countries).* It is probably a quirk in the datasets available to Carroll that geography is singled out as a separate ability whereas other specific disciplines are lumped together in broad categories. It is quite likely that a factor analysis designed to distinguish among traditional academic disciplines (e.g., chemistry vs. biology) would succeed in doing so.

5. *General science information (K1): Range of scientific knowledge (e.g., biology, physics, engineering, mechanics, electronics).* This factor is quite broad, as it encompasses all of the sciences. It is likely that each discipline within science has a narrower subfactor.

6. *Knowledge of culture (K2): Range of knowledge about the humanities (e.g., philosophy, religion, history, literature, music, and art).* As with general science information, this factor is also quite broad. It is likely that this factor has many subfactors.

7. *Mechanical knowledge (MK): Knowledge about the function, terminology, and operation of ordinary tools, machines, and equipment.* There are many tests of mechanical knowledge and reasoning used for the purpose of personnel selection (e.g., the Armed Services Vocational Aptitude Battery, the Wiesen Test of Mechanical Aptitude).

8. *Knowledge of behavioral content (BC): Knowledge or sensitivity to nonverbal human communication/interaction systems (e.g., facial expressions and gestures).* The field of emotional intelligence research is very large, but it is not yet clear which constructs of emotional intelligence should be included in CHC theory. CHC theory is about abilities rather than personality, and thus the constructs within it are measured by tests in which there are correct answers (or speeded performance). Several ability-based measures of emotion recognition and social perception exist (e.g., Advanced Clinical Solutions for the WAIS-IV and WMS-IV, the Mayer–Salovey–Caruso Emotional Intelligence Test).

Assessment Recommendations for Gkn

In most situations, Gkn is measured informally by peer reputation, but there are many educational tests that can serve as reasonable markers of specific Gkn domains.

Reading and Writing (Grw)

Definition of Grw

Reading and writing (Grw) can be defined as *the depth and breadth of knowledge and skills related to written language.* People with high Grw read with little effort and write with little difficulty. When Grw is sufficiently high, reading and writing become perfect windows for viewing a person's language development. Whatever difficulties people have understanding text or communicating clearly, it is most likely a function of Gc or Gkn. For people with low Grw, however, high language skills may not be evident in reading and writing performance. Although reading and writing are clearly distinct activities, the underlying sources of individual differences in reading and writing skills do not differentiate between the two activities cleanly. It appears that the ability that is common across all reading skills also unites all writing skills. It is important to note that when we administer tests of Grw, we are measuring much more than just Grw. Grw refers solely to the aspects of the tests that are related to reading and writing. A reading comprehension test draws on Grw, but also on Gc, Gsm, Glr, and perhaps Ga, Gs, Gf, and Gkn.

Well-Supported Narrow Abilities within Grw

1. *Reading decoding (RD): The ability to identify words from text.* Typically, this ability is assessed by oral reading tests with words arranged in ascending order of difficulty. Tests can consist of phonetically regular words (words that are spelled how they sound, such as *bathtub* or *hanger*), phonetically irregular words (words that do not sound how they are spelled, such as *sugar* or *colonel*), or phonetically regular pseudowords (fake words that conform to regular spelling rules, such as *gobbish* or *choggy*).

2. *Reading comprehension (RC): The ability to understand written discourse.* Reading comprehension is measured in a variety of ways. One common method is to have examinees read a short passage and then have them answer questions that can only be answered if the text was understood. A direct method of measuring Grw reading comprehension with reduced contamination of Gc (or Gf) is to ask questions about information that was stated directly in the text. However, we also wish to measure more complex aspects of reading comprehension, such as inference and sensitivity to the author's intent. Such skills draw deeply on Gc. A second method of measuring reading comprehension is the *cloze* technique, in which a key word has been omitted from a sentence or a paragraph. Examinees who understand what they are reading can supply the missing word.

3. *Reading speed (RS): The rate at which a person can read connected discourse with full comprehension.* There are various methods of measuring reading

speed, and there is no clear consensus about which method is best for which purposes. Should reading speed be measured by oral reading speed or silent reading speed? Should examinees be told to read as quickly as they can to measure maximal ability, or should they be told to read at their normal pace to measure their typical reading rate? How should the speed–accuracy (of comprehension) tradeoff be handled? Should the format be single words (to measure the efficiency of reading decoding) or full sentences or paragraphs (to measure the efficiency of reading comprehension)? We are certain that different kinds of reading speed tests measure different things that are important, but we are not sure exactly what is different about them. Clinicians are encouraged to think carefully about what exactly the test requires of examinees and to check to see if there is a logical connection between the apparent task demands and the referral concern. Reading speed is classified as a mixed measure of Gs (broad cognitive speed) and Grw in the hierarchical speed model (see Figure 4.5), although the amount of Gs and Grw measured most likely reflects the degree of difficulty of the reading involved in the task (e.g., reading lists of simple isolated words vs. reading short statements and indicating whether they are true or false).

4. *Spelling ability (SG): The ability to spell words.* This factor is typically measured with traditional written spelling tests. However, just as with reading decoding, it can also be measured via spelling tests consisting of phonetically regular nonsense words (e.g., *grodding*). It is worth noting that Carroll (1993) considered this factor to be weakly defined and in need of additional research.

5. *English usage (EU): Knowledge of the mechanics of writing (e.g., capitalization, punctuation, and word usage).*

6. *Writing ability (WA): The ability to use text to communicate ideas clearly.* There are various methods of assessing writing ability. Perhaps the most common method is to ask examinees to write an essay about an assigned topic. Another method is to have examinee write sentences that must include specific words or phrases (e.g., write a single sentence that includes *neither*, *although*, and *prefer*).

7. *Writing speed (WS): The ability to copy or generate text quickly.* Writing speed tasks are considered to measure both Grw and Gps (broad psychomotor speed) in the hierarchical speed hierarchy (see Figure 4.5). Similar to measures of reading speed, the relative importance of Grw or Gps probably varies, depending on the format and level of writing skills involved.

Assessment Recommendations for Grw

Much more is known about reading assessment than writing assessment. For reading, it is recommended that assessments focus on the point of reading: comprehension. If a person comprehends text well, minor weaknesses in decoding and reading speed are of secondary concern (unless the assessment concern is about reading efficiency problems rather than reading comprehension problems). If there are comprehension deficits, the assessment should focus on the proximal causes of reading comprehension problems (decoding problems, slow reading speed) and then explaining the proximal causes with more distal causes (e.g., slow naming facility → slow reading speed → slow, labored, inefficient reading → comprehension problems). We recommend measuring reading decoding with both real words and pseudowords. Reading comprehension is probably best measured with a variety of methods, including the cloze method and answering both factual and inferential questions about longer passages.

Spelling ability is an important skill (especially in a phonetically irregular language like English) and is easily measured with a traditional spelling test. It is generally a good idea to select a test that allows the clinician to be able to understand the nature of spelling problems (e.g., phonetically regular misspellings?).

Writing tests are extremely varied and probably measure a wide variety of abilities other than just specific writing abilities. Observing a child's pattern of grammar, usage, and mechanics in responses to writing tests allow clinicians to distinguish between specific writing problems and more complex problems (e.g., general language difficulties). However, it is generally a good idea to examine a wide variety of samples of the evaluee's writing, both from formal tests (e.g., the Wechsler Individual Achievement Test—Third Edition [WIAT-III]) and from school writing assignments.

Comments and Unresolved Issues Related to Grw

- *Is cloze ability meaningfully distinct from reading comprehension?* No researcher, as far as we are aware, is interested in written cloze tests as measures of anything other than reading comprehension/language comprehension. McGrew's (1999) achievement battery cross-battery CFA of different forms of reading comprehension tests (which included the WJ III cloze Passage Comprehension test) across five different samples reinforces this recommendation, as the median reading comprehension factor test loadings ranged from .83 to .85. We speculate that when cloze tests form their own factor in a factor analysis, it is primarily due to method variance. Unless compelling evidence suggests otherwise, we suggest eliminating cloze ability from the list of stratum I abilities and consider the cloze format to be what it was always intended to be: a useful alternative method of assessing reading comprehension (RC).[15]

- *What is the nature of Carroll's verbal (printed) language comprehension factor?* This factor seems to emerge when there are not enough subtests in the battery for more differentiated models to emerge. Thus this factor appears to be a more general reading factor that combines decoding tests, reading comprehension tests (both long passages and cloze-type tests), reading speed measures, and printed vocabulary tests. There is no evidence that this is a distinct ability, and thus we recommend that it be dropped from CHC theory. In the cross-battery assessment worksheets (Flanagan, Ortiz, & Alfonso, 2007), the meaning of this factor has apparently narrowed to mean written vocabulary tests. Written vocabulary tests appear to be hybrids of reading decoding and lexical knowledge, and thus it appears that this factor is redundant.

- *Is Grw really just an aspect of* Gc? Many theorists, including Carroll and Horn, group Grw with Gc. There is no doubt that Gc and Grw are closely related and not connected solely via *g*. It is also clear that Grw tests are more closely related to each other than they are to traditional Gc tests. Developmental evidence (McGrew et al., 1991; McGrew & Woodcock, 2001) reveals a markedly different growth curve for Grw when compared to Gc—a form of construct evidence suggesting that they are not identical constructs.

Quantitative Knowledge (Gq)

Definition of Gq

Quantitative knowledge (Gq) can be defined as *the depth and breadth of knowledge related to mathematics*. Gq is distinct from quantitative reasoning (a facet of Gf) in the same way that Gc is distinct from the nonquantitative aspects of Gf. It consists of acquired knowledge about mathematics, such as knowledge of mathematical symbols (e.g., $\int$, π, Σ, ∞, $\neq$, $\leq$, $+$,$-$, $\times$, $\div$, $\surd$, and many others), operations (e.g., addition–subtraction, multiplication–division, exponentiation–*n*th rooting, factorials, negation, and many others), computational procedures (e.g., long division, reducing fractions, the quadratic formula, and many others), and other math-related skills (e.g., using a calculator, math software, and other math aids). Generally measures of Gq are selected as academic achievement tests and thus must be aligned with a student's curriculum in order for the score to be diagnostic of math difficulties. This is not the case when measures of Gq are used as aptitude tests (e.g., on the SAT, GRE, or ACT). Gq is unusual in that it consists of many subskills that are fairly well defined by curriculum guides and instructional taxonomies. Thus metrics of Gq tests can be specified in relative terms (e.g., index scores) and in terms of absolute standards (e.g., an examinee can multiply two-digit numbers, can use the quadratic equation). We believe that both forms of description are necessary to paint a vivid picture of a person's Gq abilities.

Well-Supported Narrow Abilities within Gq

1. *Mathematical knowledge (KM): Range of general knowledge about mathematics, not the performance of mathematical operations or the solving of math problems.* This factor involves "what" rather than "how" knowledge (e.g., "What does π mean?" "What is the Pythagorean theorem?")

2. *Mathematical achievement (A3): Measured (tested) mathematics achievement.* There are two ways that this factor is measured. The first method is to administer math calculation problems that are decontexualized (e.g., 67 + 45 = ___). This method gets at the heart of the factor: calculation with the demands of quantitative reasoning minimized. The second method is messier but focuses on the primary goal of mathematics: solving problems. Examinees are given a scenario and a problem, and they must use reasoning to translate the word problem into a mathematically tractable solution. Examinees then use their calculation skills to arrive at a solution. For example, how many square meters of flooring are needed to cover a 6-m by 8-m rectangular room? The examinee has to intuit (or use KM) that this problem is solved by setting up the equation $6 \times 8 =$ __. Such tests clearly draw upon quantitative reasoning, a facet of Gf.

Assessment Recommendations for Gq

As with Grw, the selection of Gq tests for assessment will depend on the question being asked. Most assessments concentrate first on calculation skills and then on math problem solving. Calculation fluency is typically of secondary concern, but can yield important information about the proximal causes of calculation and problem-solving difficulties (e.g., a person who has to think about the answer to basic math facts can easily be distracted and make careless errors in the midst of an algebra problem). Math knowledge tests that have no calculation demands (e.g., WJ III Quantitative Concepts) can distinguish between people who do not know how to answer the question and people who do not know what the question is.

Comments and Unresolved Issues Related to Gq

- *Is Gq an aspect of Gc?* As originally defined by Cattell, Gq is clearly an aspect of Gc because it consists of acquired (mostly verbal) knowledge. However, since the extended Gf-Gc model was proposed, Gc has become a more narrowly focused construct, and Gq has needed to be defined separately. We propose that Gc (verbal comprehension–knowledge) is distinct from Gq, but that they are not connected solely by *g*. We believe that it is useful to think of a higher-order acquired-knowledge/expertise factor that unites Gc, Grw, Gq, and Gkn.

- *Are there more narrow Gq abilities?* Yes. Carroll (1993) only reported the narrow KM and A3 factors given their emergence in datasets that included mathematics measures in addition to the cognitive variables that were the primary target of Carroll's review. Carroll did not go out of his way to identify all possible data sets that included tests of mathematics. Thus, other Gq narrow abilities most likely exist, but have yet to be validated within the context of CHC theory. For example, there has been a recent explosion in research on "number sense" or "numerosity" (e.g., Berch, 2005; Butterworth, 2010; Fuchs et al., 2010; Hyde & Spelke, 2011; Jordon, Kaplan, Olah, & Locuniak, 2006). Lists of number sense skills vary tremendously, with Berch (2005) listing up to 30 different components. Geary (2007) suggests these primitive math competencies, which he organized into the classes of numerosity, ordinality, counting, simple arithmetic, estimation, and geometry, are rooted in biology, selected by evolutionary processes, and serve as the foundation for the development of secondary mathematics skills (e.g., KM, A3). At this time it is not clear whether number sense represents the lower developmental end of the Gq narrow abilities of KM or A3 (or RQ in Gf), represents an ability below the narrow stratum in Gq or Gf (RQ), or should be considered a narrow ability outright. Given the importance of number sense in understanding math development and disabilities (Geary, 2007) and predicting both future reading and math performance (Jordan et al., 2006), we predict the publication of a number of standardized tests of number sense competencies. Thus, we would be remiss in not mentioning the need for research to determine the appropriate placement of number sense in the evolving CHC taxonomy.

Sensory- and Motor-Linked Abilities

Cattell, Horn, and Carroll all noted that there was something different about abilities that were directly associated with sensory modalities. Despite the G in their abbreviation, they are not as general as Gf, Gsm, Glr, Gs, and Gt; yet they are still very broad. What distinguishes these broad factors from other abilities in CHC theory is that they are linked to well-defined regions and functions of the cerebral cortex (i.e., primary regions of the cerebral cortex and their associated secondary regions).

One common theme in the discussion that follows is that these abilities are hard to define. We are not used to talking about sensory-related abilities without talking about the senses and sensory acuity. The distinction between sensation and perception is relevant here, but it is not fully adequate to describe these abilities. *Sensation* refers to the detection of a stimulus. *Perception* refers to complex processing of sensory information to extract relevant information from it (i.e., literally to make *sense* of it). These abilities do encompass perception, but also refer to higher-order and goal-directed processing of sensory information (e.g., imagining how a room might look different if it were painted a darker color).

The difficulty in defining and differentiating sensory abilities is captured in a statement regarding the Gv domain, which is likely to apply to each of these sensory-based domains. According to Eliot and Czarnolewski (2007),

> One difficulty with defining spatial intelligence is that it is a dimension that is so fundamental and pervasive in people's everyday lives that they take it for granted. It is fundamental and pervasive in the sense that it may operate at any given moment at several levels of human consciousness and, in combination with other cognitive functions, may contribute to the solution process in different ways for many different types of problems. (p. 362)

Well stated!

Visual Processing (Gv)

Definition of Gv

Visual processing (Gv) can be defined as *the ability to make use of simulated mental imagery (often in conjunction with currently perceived images) to solve problems.* Once the eyes have transmitted visual information, the visual system of the brain automatically performs a large number of low-level computations (edge detection, light–dark perception, color differentiation, motion detection, etc.). The results of these low-level computations are used by various higher-order processors to infer more complex aspects of the visual image (object recognition, constructing models of spatial configuration, motion prediction, etc.). Tests measuring Gv are designed to measure individual differences in these higher-order processes as they work in tandem to perceive relevant information (e.g., a truck is approaching!) and solve problems of a visual–spatial nature (e.g., getting a large, ungainly piece of furniture through a narrow door).

Well-Supported Narrow Abilities within Gv

1. *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).* In the same way that induction is central to Gf and language development is central to Gc, this is the core ability of Gv. Almost all of the studies showing that Gv has predictive validity in forecasting important outcomes use measures of visualization as a proxy for Gv as a whole. A number of long-term longitudinal studies have shown that Gv (and visualization in particular) is an important yet often neglected precursor of high achievement in the so-called "STEM" domains (science, technology, engineering, mathematics; Lubinski, 2010; Wai, Lubinski, & Benbow, 2009).

2. *Speeded rotation (spatial relations; SR): The ability to solve problems quickly by using mental rotation of simple images.* Whereas visualization is more about the difficulty of visualizing and rotating an image, speeded rotation is about the speed at which fairly simple images can be rotated. For example, a speeded rotation test might consist of an array of letters rotated from 1 to 360 degrees. After mentally rotating the letters to an upright position, the evaluee would discover that half of the letters are backward. The test measures the speed at which the correctly oriented letters can be distinguished from the backward letters.

3. *Closure speed (CS): The ability to quickly identify a familiar meaningful visual object from incomplete (e.g., vague, partially obscured, disconnected) visual stimuli, without knowing in advance what the object is.* This ability is sometimes called *Gestalt perception* because it requires people to "fill in" unseen or missing parts of an image to visualize a single percept.

4. *Flexibility of closure (CF): Ability to identify a visual figure or pattern embedded in a complex distracting or disguised visual pattern or array, when one knows in advance what the pattern is.* This factor is primarily defined by hidden-figures tests (examinees find simple figures embedded in complex backgrounds). Horn (1980) considered this type of test to be the best marker of Gv, probably because it correlates less with Gf than do many visualization tests.

5. *Visual memory (MV): The ability to remember complex images over short periods of time (less than 30 seconds).* The tasks that define this factor involve being shown complex images and then identifying them soon after the stimulus is removed. When the stimuli are simple, are numerous, and must be remembered in sequence, it becomes more of a Gsm test than a Gv test.

6. *Spatial scanning (SS): The ability to visualize a path out of a maze or a field with many obstacles.* This factor is defined by performance on paper-and-pencil maze tasks. It is not clear whether this ability is related to complex, large-scale, real-world navigation skills.

7. *Serial perceptual integration (PI): The ability to recognize an object after only parts of it are shown in rapid succession.* Imagine that a deer is walking behind some trees and that only a part of the deer can be seen at one time. Recognizing that this is a deer is an example of what this ability allows people to do.

8. *Length estimation (LE): The ability to visually estimate the length of objects.*

9. *Perceptual illusions (IL): The ability not to be fooled by visual illusions.*

10. *Perceptual alternations (PN): Consistency in the rate of alternating between different visual perceptions.* Some people are able to look at a figure such as a Necker Cube (a figure showing the edges of a cube such that it is unclear which face is forward) and very quickly switch back and forth between imagining it from one orientation to another. Other people have much more difficulty switching their perspective. Once seen in a particular way, the interpretation of the figure becomes fixed.

11. *Imagery (IM): The ability to mentally produce very vivid images.* Recent evidence confirmed the existence of this factor as separate from visualization and other narrow Gv constructs (Burton & Fogarty, 2003). Research has suggested that mental imagery is likely to be important for surgeons, the study of human anatomy, and piloting an airplane (Thompson, Slotnick, Burrage, & Kosslyn, 2009). One can further imagine that imagery may be important for artists and designers, packing a suitcase for a trip, interpreting graphs, solving geometry problems, and other activities, but we do not have compelling evidence that this is so. Small-scale brain imaging studies have suggested that visual spatial imagery may not be a single faculty; rather, "visualizing spatial location and mentally transforming locating rely on distinct neural networks" (Thompson et al., 2009, p. 1245). This research suggests a distinction between *transformational processing* and *memory for location*. An *objective* versus *spatial* imagery dichotomy has also been suggested (see Thompson et al., 2009), as well as the possibility of *quality* versus *speed* of imagery abilities (Burton & Fogarty, 2003). We believe that imagery is a promising CHC ability warranting more theoretical and psychometric research attention. We would not be surprised to see multiple imagery abilities validated. More importantly, if psychometrically well-developed practical imagery measures can be constructed, there is a good chance that they will be found to have diagnostic or predictive importance in select educational and occupational domains.

Assessment Recommendations for Gv

Adequate measurement of Gv should always include measures of visualization. If a visualization test utilizes manipulatives, it is important for it to minimize motor requirements (Gp, Gps). The physical manipulation of objects is not required to measure "in the mind's eye" visualization (see, e.g., the WJ III Spatial Relations and Block Rotation tests). If speeded tasks are used, they should be balanced by the inclusion of unspeeded tasks.

Comments and Unresolved Issues Related to Gv

- *Is visualization part of Gf?* In many factor-analytic studies, Gf is defined in part by tests considered to measure visualization (e.g., Woodcock, 1990). In Carroll's (1993) analyses, visualization tests often loaded on both Gf and Gv, and about a third of the time the loadings were higher on Gf. What might be happening? Studies of visualization tests suggest that people use a variety of strategies on spatial tests (Kyllonen, Lohman, & Woltz, 1984). Hegarty (2010) has classified these strategies broadly as either using mental imagery (on the Paper Folding Test: "I imagined folding the paper, punching the hole, and unfolding the paper in my mind") or analytic strategies (e.g., "I used the number of holes/folds to eliminate some of the answer choices"). We believe that the Gv loadings for visualization tests occur because many people use imagery to complete the tests some of the time, and that the Gf loadings occur because logical/analytic strategies are also employed by some people. Furthermore, Kyllonen and colleagues (1984) found that the best performers on visualization tests were flexible in their strategy use, adapting to the task demands of a particular item. This kind of judgment is invariably associated with Gf.
- *Why has the SR factor changed its name from spatial relations to speeded rotation?* Carroll defined the spatial relations factor by using Lohman's (1979) name and definition. Because Lohman, Pellegrino, Alderton, and Regian (1987) suggested that a better name might be "speeded rotation or reflection" (p. 267), Carroll (1993, p. 326) considered naming it that. Carroll acknowledged that all aspects of Gv deal with spatial relations, and thus the term *spatial relations* does not capture what is unique about the factor. Lohman (1996) subsequently renamed the factor *speeded rotation*, and we believe that it is time to make this switch as well. The term *spatial relations* has been used by many researchers to mean a variety of things, including what is meant by visualization. *Speeded rotation* is more descriptive of what the factor is and is thus

more easily remembered. Fortuitously, it can keep the same abbreviation of SR. We believe that most of the SR (spatial relations) narrow-ability classifications of Gv tests during the first- and second-generation CHC development periods (see Figure 4.1) are wrong, and the second author offers his *mea culpas*.

• *Do spatial navigation abilities belong with Gv?* Many aspects of Gv are still unexplored. It seems highly likely that *spatial navigation ability*, defined here as the ability to find one's way and maintain a sense of direction and location while moving around in a complex real-world environment (Wolbers & Hegarty, 2010), should factor with Gv (Schoenfeld, Lehmann, & Leplow, 2010). Jansen's (2009) distinction between "small-scale" spatial abilities (visualization, mental rotation abilities as per the current CHC Gv domain) and "large-scale" spatial abilities (abilities involved in moving around a space that is not visible from the observer's standpoint)—latent factor abilities that correlated at a significant but low .30 in Wolbers and Hegarty's (2010) research—may prove useful in future research in this area. With the advent of 3-D computer graphics and virtual-reality software, we expect to see a variety of more realistic Gv tests.

Auditory Processing (Ga)

Definition of Ga

Auditory processing (Ga) can be defined as *the ability to detect and process meaningful nonverbal information in sound*. This definition is bound to cause confusion because we do not have a well developed vocabulary for talking about sound unless we are talking about speech sounds or music. Ga encompasses both of these domains, but also much more. There are two common misperceptions about Ga. First, although Ga depends on sensory input, it is not sensory input itself. Ga is what the brain does with sensory information from the ear, sometimes long after a sound has been heard (e.g., after he became deaf, Beethoven composed some of his best work by imagining how sounds would blend). The second extremely common misconception, even among professionals, is that Ga is oral language comprehension. It is true that one aspect of Ga (parsing speech sounds, or phonetic coding) is related to oral language comprehension—but this is simply a precursor to comprehension, not comprehension itself (in the same way that adequate vision is a prerequisite for playing tennis, but vision is not normally thought of as a tennis skill).

If Gc is the wallflower (Hunt, 2000) at the CHC ball, then Ga is an adolescent social butterfly flitting from factor to factor, not readily defined or understood by others, and still in an awkward formative stage of adolescent theoretical and psychometric identity formation (with notable identity role confusion). Ga was the least studied factor in Carroll's (1993) treatise, largely because reliable and valid technology for measuring Ga abilities did not exist during most of the days of prolific psychometric factor-analytic research. This situation has been recently remedied by an explosion of wide-ranging (but not necessarily internally coherent or organized) research on a wide array of Ga characteristics (see Conway, Pisoni, & Kronenberger, 2009; Gathercole, 2006; Hubbard, 2010; Rammsayer & Brandler, 2007).

Well-Supported Narrow Abilities within Ga

1. *Phonetic coding (PC): The ability to hear phonemes distinctly*. This ability is also referred to as *phonological processing, phonological awareness, and phonemic awareness*. People with poor phonetic coding have difficulty hearing the internal structure of sound in words. This makes sounding out unfamiliar words while reading difficult. Poor phonetic coding is one of the major risk factors in reading disorders, specifically phonological dyslexia. Most people, even with very low Ga, can understand speech and speak perfectly well without awareness of the distinct phonemes they are hearing and saying. What they lack is the ability to separate phonemes mentally and hear them in isolation.

2. *Speech sound discrimination (US): The ability to detect and discriminate differences in speech sounds (other than phonemes) under conditions of little or no distraction or distortion*. The definition of this factor has been narrowed to nonphonemic aspects of speech sounds, in order to make it more distinct from phonetic coding. People who have poor speech sound discrimination are less able to distinguish variations in tone, timbre, and pitch in speech; this might reduce their ability to detect subtle emotional changes, or subtle changes in meaning due to differential emphasis.

3. *Resistance to auditory stimulus distortion (UR): The ability to hear words correctly even under con-*

ditions of distortion or loud background noise. It is not yet clear to what degree this ability depends on sensory acuity. As people age, they tend to complain that they have greater difficulty understanding speech in noisy public places or on a telephone with background noise. Speaking louder usually helps them understand better.

4. *Memory for sound patterns (UM): The ability to retain (on a short-term basis) auditory events such as tones, tonal patterns, and voices*. This ability is important for musicians, who need to be able to hold in mind a musical phrase they hear so that they can reproduce it later.

5. *Maintaining and judging rhythm (U8): The ability to recognize and maintain a musical beat*. This may be an aspect of memory for sound patterns, as short-term memory is clearly involved. However, it is likely that there is something distinct about rhythm that warrants a distinction. Future research is needed.

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

7. *Absolute pitch (UP): The ability to perfectly identify the pitch of tones*. As a historical tidbit, John Carroll had perfect pitch.

8. *Sound localization (UL): The ability to localize heard sounds in space*.

Assessment Recommendations for Ga

Ga may be unusual in CHC theory, in that psychologists are more interested in a narrow ability (phonetic coding) than in the broad ability (Ga). Some of the other Ga abilities are clearly related to musical achievement and are priorities if one is attempting to assess musical aptitude, or assess impairment for a brain-injured musician. We see promise for some yet to be clearly identified and understood Ga abilities (e.g., auditory imagery; auditory-based temporal processing measures; auditory gap detection; rhythm perception and production) for understanding general cognitive and language development.

Comments and Unresolved Issues Related to Ga

- *Does Carroll's (1993) temporal tracking (UK) belong in Ga?* Previously, this factor was listed as part of Ga. *Temporal tracking* was defined as the ability to mentally track auditory temporal (sequential) events so as to be able to count, anticipate, or rearrange them (e.g., reorder a set of musical tones). This factor is measured by tests that require simultaneous storage and processing; thus it appears that such tests are methods of measuring working memory capacity (Stankov, 2000).[16]
- *Do Carroll's (1993) hearing and speech threshold (UA UT UU), sound frequency discrimination (U5), sound intensity/duration discrimination (U6), and general sound discrimination (U3) factors belong in CHC theory?* These are sensory acuity factors, and as such are outside the scope of CHC theory.

Olfactory Abilities (Go)

Definition of Go

Olfactory abilities (Go) can be defined as *the abilities to detect and process meaningful information in odors*. Go refers not to sensitivity of the olfactory system, but to the cognition one does with whatever information the nose is able to send. The Go domain is likely to contain many more narrow abilities than currently listed in the CHC model, as a cursory skim of Go-related articles reveals reference to such abilities as olfactory memory, episodic odor memory, olfactory sensitivity, odor specific abilities, odor identification and detection, odor naming, and olfactory imagery, to name but a few. Among the reasons why the Minnesota Multiphasic Personality Inventory has items about "peculiar odors" are that distorted and hallucinatory olfaction is a common early symptom of schizophrenia, and that poor olfaction is an associated characteristic of a wide variety of brain injuries, diseases and disorders (Doty, 2001; Dulay, Gesteland, Shear, Ritchey, & Frank, 2008). Clearly, olfactory processing is easily damaged and often acts as a "canary in the coal mine" for neurological insult or decline.

Hypothesized Narrow Abilities within Go

1. *Olfactory memory (OM): The ability to recognize previously encountered distinctive odors*. The oft-noted experience of smelling a distinctive smell and being flooded with vivid memories of the last time that odor was encountered does have some basis in research. Memory for distinctive odors has a much flatter forgetting curve than many other kinds of memory (Danthiir, Roberts, Pallier, & Stankov, 2001).

Assessment Recommendations for Go

Most practical and clinical applications of smell tests are actually sensory acuity tests. People who work where gas leaks are possible must be tested regularly to make sure that they can make potentially life-saving odor detections.

Comments and Unresolved Issues Related to Go

- *Does olfactory sensitivity (OS) belong in CHC theory?* This is the ability to detect and discriminate differences in odors. That is, it is a sensory acuity factor, and we believe it is thus outside the scope of CHC theory.
- *What about olfactory knowledge?* Surely there is an ability to name smells! There probably is, but it turns out that "blind" smelling identification tests are extremely difficult for most people. Fans of the television program *Top Chef* know that even high-end professional chefs are often laughably bad at identifying the smells of spices that the chefs work with daily. We await innovations in measurement and well-designed studies to include such a factor.

Tactile Abilities (Gh)

Definition of Gh

Tactile abilities (Gh) can be defined as the abilities to detect and process meaningful information in haptic (touch) sensations. Gh refers not to sensitivity of touch, but to the cognition one does with tactile sensations. Because this ability is not yet well defined and understood, it is hard to describe it authoritatively. We can speculate that it will include such things as tactile visualization (object identification via palpation), tactile localization (i.e., where has one been touched), tactile memory (i.e., remembering where one has been touched), texture knowledge (naming surfaces and fabrics by touch), and many others. Tests of Gh have long been used in neuropsychological batteries because of their ability to detect brain injury, especially to the somatosensory cortex.

Well-Supported Narrow Abilities within Gh

There are no well-supported cognitive ability factors within Gh yet. *Tactile sensitivity (TS)*, a sensory acuity ability, refers to the ability to make fine discriminations in haptic sensations. For example, if two caliper points are placed on the skin simultaneously, we perceive them as a single point if they are close together. Some people are able to make finer discriminations than others.

Assessment Recommendations for Gh

Most practical and clinical applications of Gh tests actually use sensory acuity tests. There are no currently available tests of higher-order Gh processes that are clearly distinct from Gv. The Halstead–Reitan Neuropsychological Test Battery and the Dean–Woodcock Neuropsychological Battery include a number of Gh tests.

Comments and Unresolved Issues Related to Gh

- *How is Gh to be distinguished from Gv and Gf?* Two well-designed studies (Roberts, Stankov, Pallier, & Dolph, 1997; Stankov, Seizova-Cajic, & Roberts, 2001) found it difficult to distinguish between complex tests assumed to measure Gh and well-defined markers of Gv and Gf. Why might this be so? If the test involves identifying common objects (coins, keys, books, etc.) by handling them while blindfolded, the examinee is essentially using the hands instead of the eyes to *visualize* an object.

Kinesthetic Abilities (Gk)

Definition of Gk

Kinesthetic abilities (Gk) can be defined as *the abilities to detect and process meaningful information in proprioceptive sensations. Proprioception* refers to the ability to detect limb position and movement via *proprioreceptors* (sensory organs in muscles and ligaments that detect stretching). Gk refers not to the sensitivity of proprioception, but to the cognition one does with proprioceptive sensations. Because this ability is not yet well understood, we can only speculate that it will include such things as a dancer's ability to move into a certain position and visualize how it looks to another person (which would have Gv components), and knowledge of which body movements will be needed to accomplish a specific goal (e.g., passing through a narrow space). Such abilities are likely to be involved in Gardner's *bodily–kinesthetic intelligence* (see Chen & Gardner, Chapter 5, this volume).

One interesting possibility is that proprioceptive receptors and other mechanoreceptors in muscles are used in inferring characteristics of objects that are hefted and wielded (Turvey, 1996). That is, when an object is held and waved about (*dynamic touch*), one can get a sense of its length, weight, and mass distribution. Higher-order cognition occurs when this information informs potential uses (*affordances*) of the object (e.g., a hammer, a lever, a weapon).

Well-Supported Narrow Abilities within Gk

There are no well-supported cognitive ability factors within Gk yet. *Kinesthetic sensitivity (KS)*, a sensory acuity ability, refers to the ability to make fine discriminations in proprioceptive sensations (e.g., whether and how much a limb has been moved).

Assessment Recommendations for Gk

We are unaware of commercially available measures of Gk. Very little is known about the measurement of Gk. Readers are referred to Stankov and colleagues (2001) for ideas about Gk tests.

Comments and Unresolved Issues Related to Gk

- *How separate is Gk from Gp?* We suspect that Gk and Gp are so interconnected that they may form the same broad-ability construct. That is, although there is a clear physiological distinction between motor abilities and kinesthetic perception, motor performance is constantly informed by sensory feedback, and thus Gk and Gp can be considered an integrated functional unit.

Psychomotor Abilities (Gp)

Definition of Gp

Psychomotor abilities (Gp) can be defined as *the abilities to perform physical body motor movements (e.g., movement of fingers, hands, legs) with precision, coordination, or strength.*

Well-Supported Narrow Abilities within Gp

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

2. *Multilimb coordination (P6): The ability to make quick specific or discrete motor movements of the arms or legs.*

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

4. *Manual dexterity (P1): The ability to make precisely coordinated movements of a hand or a hand and the attached arm.*

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

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

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

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

Assessment Recommendations for Gp

Psychologists are not usually interested in Gp for its own sake. Neuropsychologists use measures of Gp, such as various grip tests and pegboard tests, to measure uneven performance with the right and left hands as an indicator of lateralized brain injury. Industrial/organizational psychologists may use Gp measures for personnel selection in jobs that require manual dexterity. Occupational and physical therapists use measures of motor functioning with consistent regularity.

CHC THEORY VISUALIZED

In writing this chapter, we have become sensitized to the need for an overarching framework with which to understand CHC theory as a whole. When CHC theory consisted of 8–10 broad abilities, the sense of information overload it created upon initial encounter was already severe. Now that CHC theory consists of 16 broad abilities, the problem has increased exponentially. Some organizing principles are needed to manage the complexity of the taxonomy. In Figure 4.7, we show some higher-order groupings of the broad abilities in CHC theory. Some of these groupings (with solid boxes and overlapping ovals) are functional in nature. For example, Gsm and Glr have a common purpose. Some ability groupings (with dotted boxes) are merely conceptual groupings (e.g.,

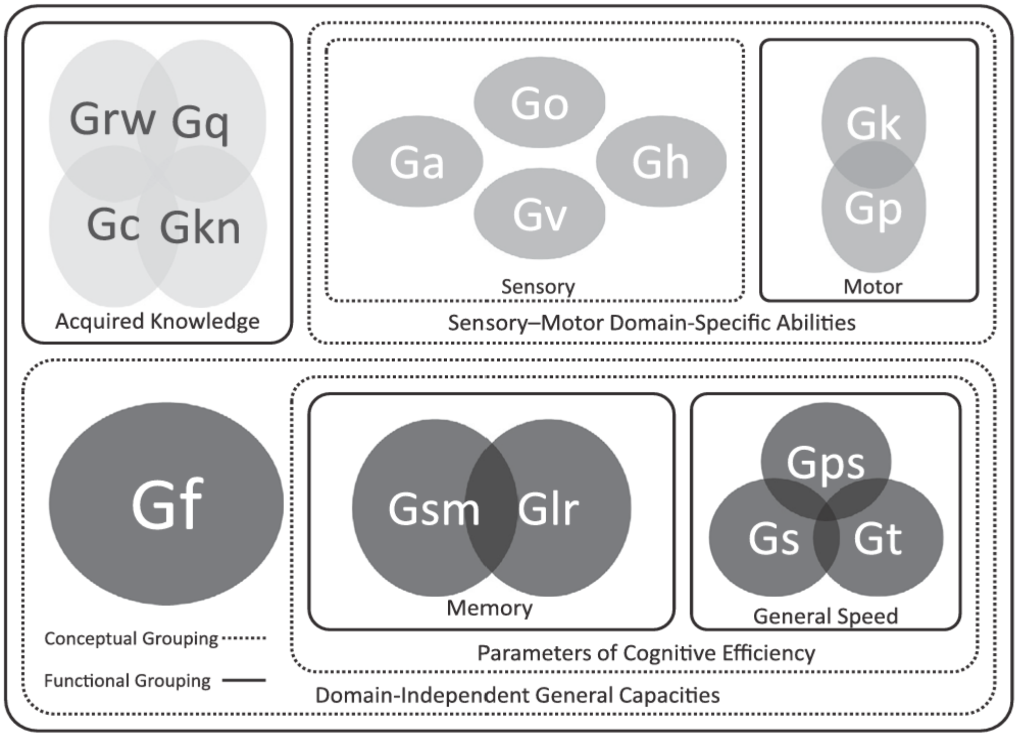

FIGURE 4.7. Conceptual and functional groupings of broad CHC abilities.

some abilities are related to sensory or motor functions).

In Figure 4.8, we present a highly speculative model of how CHC broad abilities might function as parameters of information processing. We have borrowed liberally from the information-processing models by Woodcock (1993) and Kyllonen (2002). We acknowledge that this information-processing model is not exactly cutting-edge, compared to current work in experimental cognitive psychology. However, we hope it stimulates research and theory that integrates knowledge from research on individual differences and experimental cognitive psychology.

The arrows represent the flow of information through different information-processing structures (represented as boxes). These structures are assumed to be invariant across normal humans, but their parameters (e.g., efficiency, speed, capacity, breadth, and power) differ from person to person. These parameters are hypothesized to map onto CHC constructs.

Information enters the mind via sensory receptors. Some people have more acute sensory receptors than others (and this varies from one sensory system to the other). The various sensory-linked abilities (Gv, Ga, Go, Gh, Gk) determine the complexity of perceptual processing possible for any given person. Greater complexity of perceptual processing allows some people to perceive more nuance and complexity in everything. Gs and Gt represent general constraints on the speed of perception. Gsm places asymptotic limits on the capacity of working memory and the degree to which attention can be controlled within working memory. Gf and Gsm jointly determine the complexity of thought that is possible within working memory.

Glr learning efficiency determines how much effort is needed to store new information (of various kinds) in long-term memory. Gc, Gkn, Grw, and Gq are indices of the breadth of declarative knowledge stored in long-term memory. Nonverbal (procedural) knowledge is also presented, but little is known about its measurement. In part, the breadth of procedural knowledge may represent the degree to which the sensory–motor-linked abilities are influenced ("crystallized") by experience. For example, exposure to a particular language sensitizes us to perceive certain phonemes (part of Ga) and not others.

Glr retrieval fluency represents the speed at which information in long-term storage can be

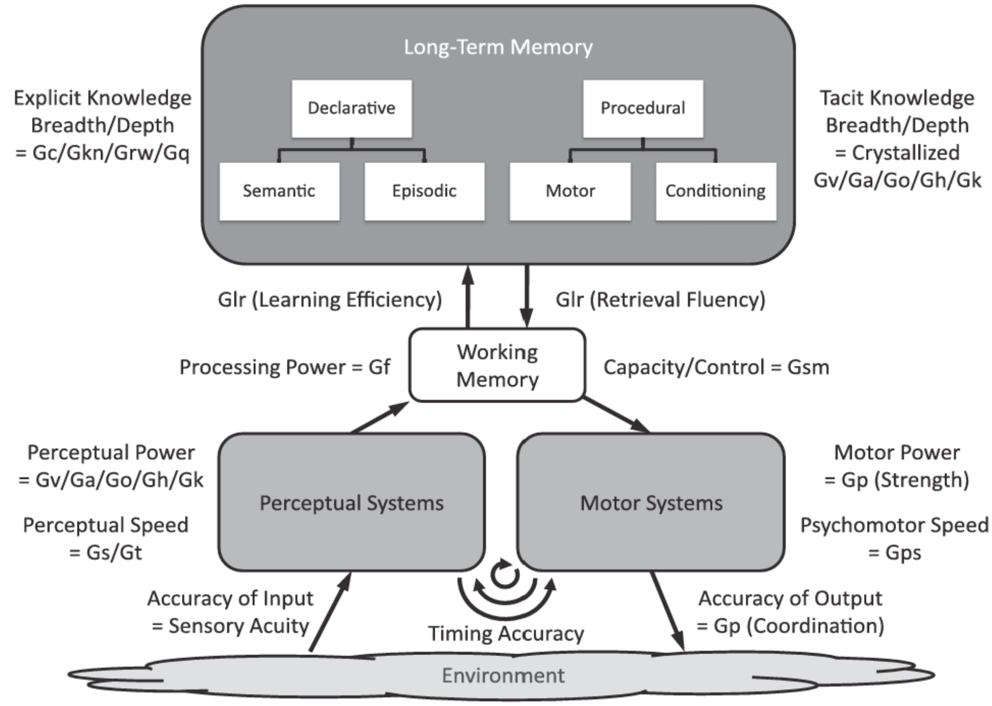

FIGURE 4.8. CHC abilities as parameters of information processing.

loaded into working memory structures for further cognitive processing and use. Gps represents the speed at which the central executive in working memory can execute motor commands. Gp represents parameters of motor performance, such as strength, coordination, and control. The accuracy of motor movement is thus analogous to sensory acuity. What would be analogous to Gv or Ga in the motor domain? It is not clear that there *must* be something, but it may have something to do with the complexity of movement possible for a person. Finally, because Kyllonen (2002) noted that perceptual and motor systems are constantly in dialogue, we represent differences in the accuracy and timing of this communication with the curved arrows. We speculate that individual differences in the accuracy and calibration of cerebellar and other brain-based timing mechanisms may turn out to be important determinants of cognitive and motor performance.[17]

Focusing on a subset of CHC abilities, in Figure 4.9 we present a conceptual map of how the four acquired-knowledge broad abilities may be related. This map is not a structural model (as seen in structural equation models), but rather a loose interpretation of ideas presented by Carroll (1993) and Ackerman (1996). At the top of the conceptual map is all acquired knowledge, much of which is nonverbal (e.g., how to ride a bicycle). Acquired knowledge consists also of Gc and the two academic abilities, Grw and Gq. Gc is divided into two broad classes, language development and general information. Language development consists of many abilities, which can be roughly categorized by the degree to which the ability is oral or written and by the degree to which the language ability involves understanding language (receptive skills) or communicating with language (productive skills). The 2×2 matrix under language development is loosely based on a figure drawn by Carroll (1993, p. 147).

Under general information, we present Gkn (domain-specific knowledge). People who have broad Gc interests and knowledge are also likely to develop deep specialized knowledge in their particular field of interests. Gkn's symbol is empty because, by definition, Gkn is specialized, not unified. Because skills in Gkn develop according to specific interests and work experiences, we have drawn Gkn as a hexagon in honor of Holland's (1985) "RIASEC" (realistic, investigative, artistic, social, enterprising, and conventional) model of career interests. Holland's model is to the structure of interests what CHC theory is to cognitive

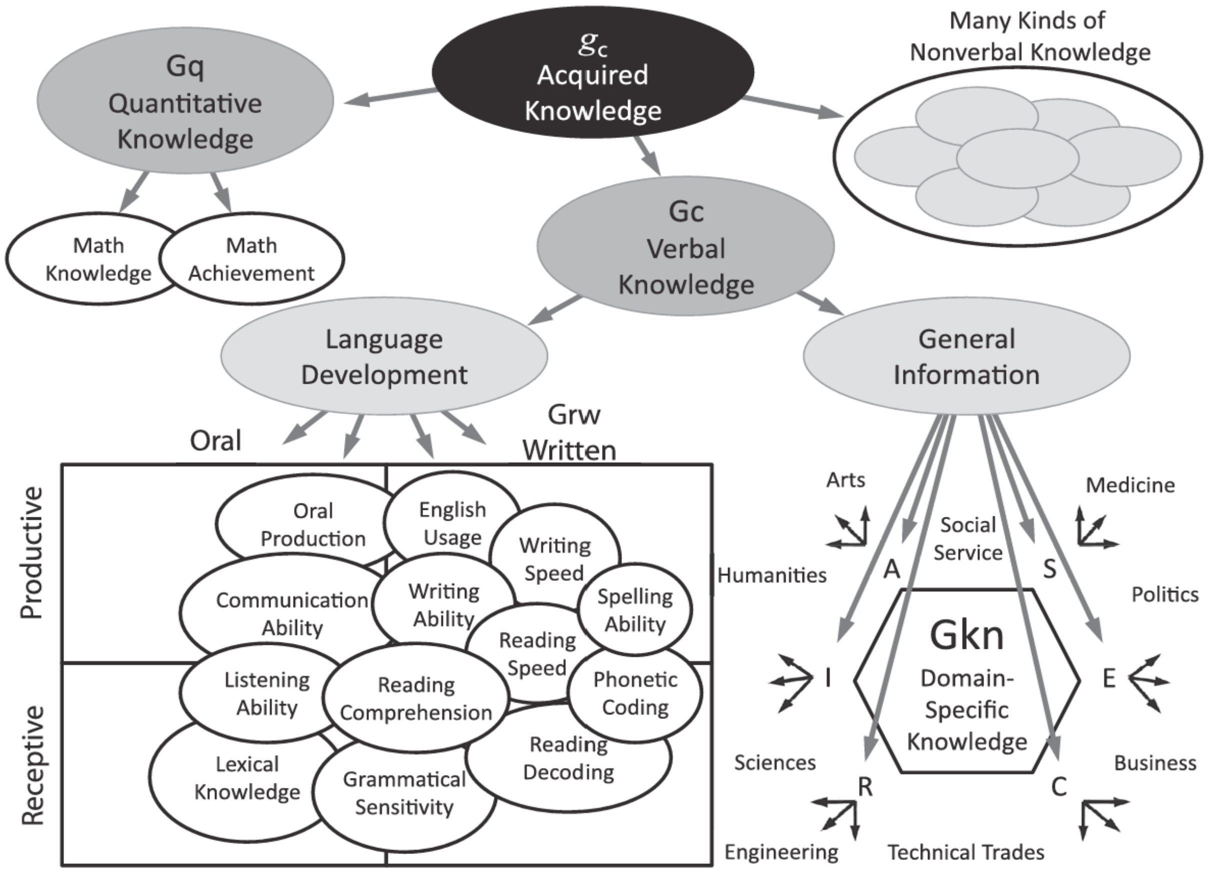

FIGURE 4.9. Conceptual map of acquired knowledge.

abilities. Holland's model suggests that interests that are adjacent to each other (e.g., social and enterprising interests) are likely to co-occur in the same person, and that interests that are further apart are less likely to co-occur in the same person (e.g., conventional and artistic interests). Once a person settles into a specific career path, his or her knowledge becomes extremely focused, symbolized by the scattering arrows jutting out from each of Holland's "big six" interests.

THE FUTURE EVOLUTION OF CHC THEORY

When the merger of the ideas of Cattell, Horn, and Carroll was first proposed by McGrew (1997), the hope was to facilitate the transfer of knowledge from these great thinkers to psychoeducational assessment practitioners. Gratifyingly, this hope has been realized in many ways. Had the purpose of CHC theory been simply to summarize the work of these grand masters of intelligence theory, the theory would quickly cease to be relevant, as new research causes older concepts to be refined or even superannuated. The ultimate goal, however, has always been for CHC theory to undergo continual upgrades, so that it would evolve toward an ever-more accurate summary of human cognitive diversity. With that end in mind, we have attempted to simplify the model where it needed simplification. We have also elaborated upon aspects of the model that needed elaboration. We hope that our research- and reasoning-based conclusions and hypotheses will make CHC theory more accurate, more understandable to practitioners, and ultimately more helpful to people who undergo psychoeducational assessment. We hope that many readers, especially long-time CHC users and researchers, are placed into a state of thoughtful disequilibrium regarding their understanding of the prevailing CHC model. Even if such users are unconvinced by our arguments, if the schemas of CHC users are broadened and refined by considering the ideas we have presented, our chapter will have been a success. The original source theorists of CHC theory would not idly stand by and let the current consensus-based theory calcify and suffer from hardening of the CHC categories. We believe that Cattell, Horn, and Carroll, and all the psychometric giants upon whose shoulders they stood, would smile on our efforts—and would then promptly engage us, and others, in spirited debates and empirical- and theory-based discourse.

NOTES

1. A *taxonomy* is a system of classification.
2. The "Factor Analysis at 100: Historical Developments and Future Directions" conference, held at the Thurstone Psychometric Laboratory, University of Carolina at Chapel Hill, May 13–15, 2004, produced a book and two interesting visual summaries of the factor analysis "genealogy" (academic backgrounds and relationships among individuals who have contributed to the field of factor analysis) and a timeline (significant publications in events in the 100-year history of factor analysis). Information is available online (*www.fa100.info*).
3. Different sources (Carroll, 1993; Horn & Noll, 1997; Jensen, 1998) list between seven and nine abilities, and also provide slightly different names for the Thurstone PMAs.
4. Cattell's original g_f-g_c notation utilized lowercase italic *g*'s followed by subscripts. As described later in the chapter, these eventually changed to uppercase G (general) roman letters followed by lowercase letters that designated the specific cognitive ability domains. From this point forward in this chapter, the later convention is used.
5. Cattell (1963) was so excited by Horn's (1965) dissertation that he referenced many of its findings before it was even finished.
6. About Thurstone's PMA model, Horn and Noll (1997) noted that "to a considerable extent, modern hierarchical theories derive from this theory" (p. 62).
7. See McGrew (1997, 2005) for a discussion of the model differences.
8. A so-called "tipping point" is the "moment of critical mass, the threshold, the boiling point" (Gladwell, 2000, p. 12) where a movement that has been building over time, generally in small groups and networks, begins to influence a much wider audience.
9. The data in Figure 4.2 represent two different literature databases. The search terms *CHC* and *Cattell–Horn–Carroll* were submitted to the *PsycINFO* and the journal *Intelligence* reference archives. The searches identified any publications (journal articles, books, dissertations) where the two search terms occurred anywhere in the source (title, text, or references).
10. Background information and explanations of the evolution of McGrew's "beyond CHC theory" model work can be found online (*www.iqscorner.com/2010/10/pushing-edge-of-contemporary-cognitive.html*).
11. There is no such thing as reasoning that is completely independent of prior learning (Horn, 1985).
12. These recommendations are not based on hard evidence, but rather on our measured opinions. They do not obviate the need for sound clinical judgment. If there are specific referral concerns that require something other than what is recommended here, common sense should prevail.
13. Gsm is sometimes referred to as *working memory*, but we reserve this term to refer to Baddeley's (1986) theory of theoretical entities within short-term memory (central executive, phonological–articulatory loop, etc.). That is, there is a difference between a theory about species-invariant features of memory (i.e., working memory) and individual differences in the capacity and efficiency of those features (McGrew, 2005).
14. This factor was previously named *working memory*. However, as explained in McGrew (2005), this term does not refer to an individual-difference variable. *Working memory capacity* is an individual-difference variable, that is, a property of the working memory system as a whole.
15. Parallels for our hypothesis exist in all CHC domains. For example, the WJ III Concept Formation test is a miniature conceptual rule-learning task that includes corrective feedback. It has been established as a strong indicator of Gf I (induction). Most geometric or figural matrices tests similarly have been found to be strong indicators of Gf I (induction). Differences in performance between these two types of induction measures are likely due to the different methods used, unreliability inherent in each measure, and possible small amounts of reliable specific or unique variance.
16. McGrew attended the 1989 Minnesota Symposium on Learning and Individual Differences, and saw and heard Lazar Stankov stand up from his seat in the audience after listening to a presenter talk in detail about working memory, and make a strongly worded minispeech that the temporal tracking ability he and Horn had identified in 1980 (Stankov & Horn, 1980) should receive proper credit as being the first identification of what is now known as working memory.
17. A number of brain regions have been implicated in mental interval timing. These include, but are not limited to, the cerebellum, dorsolateral pre-

frontal cortex, parietal cortex, basal ganglia, and supplemental motor cortex. These brain areas are hypothesized to work together in a synchronized brain circuit or network to control precise mental timing and coordination of a wide array of cognitive and sensory–motor functions. The breadth of this mental timing literature is tremendous, with numerous "brain clock" models having been proposed and studied. Recent research by Rammsayer and colleagues has gone as far as suggesting that auditory-based temporal processing may be the essence of psychometric *g*, more so than traditional Jensenian-led research on reaction time *g*. This "IQ brain clock" literature is so large that McGrew devotes a special blog to reporting research on mental timing (the IQ Brain Clock blog; *ticktockbraintalk.blogspot.com*).

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