Validation of the Functional Cattell Horn Carroll (F-CHC) Theoretical Nomenclature

Denise E. Maricle, Ph.D.

Denise E. Maricle, Ph.D.
Professor
School Psychology Doctoral Program
Department of Psychology and Philosophy
CFO 807B, 1315 Bell Avenue
Texas Woman's University
Denton, TX 76204
dmaricle@twu.edu
940-898-2260

Validation of the Functional Cattell Horn Carroll (F-CHC) Theoretical Nomenclature

The Cattell-Horn-Carroll (CHC) theory is the contemporary theoretical orientation supporting the current understanding of cognitive functioning and neurocognitive assessment. CHC theory emerged in the late 1990's from the historical precedents of Gf-Gc theory (Cattell, 1963; Horn, 1965; Horn & Cattell, 1966; Horn & Noll, 1997) and Carroll's factor analytic theory (Carroll 1993; Carroll, 2003). The two theories were consolidated at the suggestion of Kevin McGrew into one theory with three hierarchical stratums: a broad general ability or "g" factor, nine broad ability factors, and multiple narrow abilities. Over the last 20 years, McGrew's research with CHC and his classifications of CHC abilities have become the standard framework for discussing and applying CHC theory. CHC has become the pre-eminent interpretive framework for measures of intellectual functioning and is currently the most accepted psychometric model for the structure of human cognitive abilities and its' measurement (Keith & Reynolds, 2010; Schneider & McGrew, 2012).

Over the course of the last five years, changes to the theory have been proposed (Schneider & McGrew, 2012, 2018). McGrew developed his CHC Periodic Table of Human Abilities (McGrew, LaForte, & Schrank, 2014) to represent a scientific taxonomy of human cognitive abilities. Schneider and McGrew (2012, 2018) re-conceptualized the CHC broad and narrow abilities and suggested structural and functional changes to the theory, including positing that a joint neuropsychological and CHC perspective might be the new frontier for understanding cognitive constructs and assessing cognitive performance and abilities (McGrew, 2016). In 2018, Schneider and McGrew presented their most recent re-conceptualization of CHC theory, speculating that research suggests that more broad abilities be considered (up to 16 total), along with their corresponding narrow abilities as being within the scope of the theory.

In 2013, Miller conceptualized this joint neuropsychological and CHC perspective in his Integrated School Neuropsychology/Cattell-Horn-Carrol Conceptual Model (Integrated SNP/CHC Model). Miller's model hypothesizes four broad classifications that are further segmented into second order and third order classifications (basically denoting broad order factors and narrow abilities). Research by Flanagan, Alfonso, Ortiz, and Dynda (2010), as well as Flanagan, Ortiz, and Alfonso (2013) supports a joint neuropsychological/CHC interpretive perspective, although their conceptualization resembles the more traditional CHC model.

The widespread application of CHC theory to assessment and interpretation has given rise to a specialized vocabulary or more scientific nomenclature/taxonomy. While scientific and specific nomenclatures provide necessary precision for the scientific community, the terminology can be confusing or incomprehensible to the community of individuals most in need of the information, such as parents and teachers. For the average clinician trying to apply the CHC framework to assessment and interpretation, the complexity of the scientific taxonomy and the human cognitive abilities purportedly measured by CHC theory can seem overwhelming. Many clinicians find it difficult to describe and/or explain current CHC conceptualizations and what they mean for a child's assessment and learning performance.

In 2017, Woodcock, Miller, Maricle and McGill proposed a functional reconceptualization of CHC theory which they labeled F-CHC. The F-CHC framework is thought to be a more parsimonious structure that is consistent with recent neurocognitive research, more functional and practical for the average clinician, and more understandable to consumers of the information. Woodcock and colleagues recommend grouping the cognitive abilities denoting CHC factors into three broad conceptual domains: Acquired Knowledge, Thinking Abilities, and Cognitive Efficiency; and reducing multiple narrow abilities applicable to each CHC factor to two primary narrow abilities for each factor. For example, in this F-CHC conceptualization the first domain of Acquired Knowledge consists of the CHC factors of Comprehension-Knowledge (Gc), Reading and Writing (Grw) and Quantitative Reasoning (Gq). Woodcock and colleagues split the Reading and Writing (Grw) factor into separate domains (e.g. Reading: Grw-R and Writing: Grw-W) and re-labeled Quantitative Reasoning (Gq) as Mathematics. Additionally, the narrow abilities contributing to each broad domain or factor, were collapsed or reconfigured into two narrow abilities for each broad domain. For example, the four narrow abilities under Comprehension Knowledge (language development, listening ability, general verbal information and lexical knowledge) were collapsed and combined into two narrow abilities, Verbal Ability (Gc-VA), and Factual Knowledge (Gc-K). The proposed structure of the F-CHC nomenclature can be seen in Figure 1.

Figure 1. Functional CHC (F-CHC) Nomenclature

FUNCTIONAL CHC (F-CHC) NOMENTCLATURE	
Broad Factors	Narrow Abilities
Acquired Knowledge	
Comprehension-Knowledge *(Gc)*	Verbal Ability *(Gc-VA)*
	Factual Knowledge *(Gc-K)*
Reading *(Grw-R)*	Reading Skills *(Grw-RS)*
	Reading Comprehension *(Grw-RC)*
Writing *(Grw-W)*	Writing Skills *(Grw-WS)*
Mathematics *(Gq)*	Calculation *(Gq-C)*
	Applied Math *(Gq-AP)*
Psychomotor Abilities *(Gp)*	Handwriting *(Gp)*
Thinking Abilities	
Visual Spatial Processing *(Gv)*	Pictorial Processing *(Gv-PP)*
	Spatial Procession *(Gv-SP)*
Auditory Processing *(Ga)*	Sound Discrimination *(Ga-SD)*
	Phonetics *(Ga-Ph)*
Learning-Memory *(Glm)*	Immediate Recall *(Glm-IR)*
	Memory Retrieval *(Glm-MR)*
Reasoning *(Gr)*	Contextual Reasoning *(Gr-CR)*
	Inductive/Deductive Reasoning *(Gr-ID)*
Cognitive Efficiency	
Conscious Memory *(Gcm)*	Memory Span *(Gcm-MS)*
	Working Memory *(Gcm-WM)*
Cognitive Processing Speed *(Gs)*	Perceptual Speed *(Gs-PS)*
	Thinking Speed *(Gs-TS)*

Research Design and Methodology

Now that the F-CHC model has been proposed it is necessary to validate the model and subject the model to rigorous research to confirm or disconfirm the model's tenets. Preliminary data analysis conducted by Woodcock and colleagues (2017) suggests that factor analysis would yield a structure supportive of the proposed F-CHC model.

Thus, the purpose of this study was to conduct a broad preliminary examination of the validity of the F-CHC model. The following question and attendant hypotheses were proposed:

RQ: Does the proposed F-CHC model explain the underlying or latent structure of human abilities as measured by data from the WJ III.

RH 1: The data will support the proposed F-CHC model.

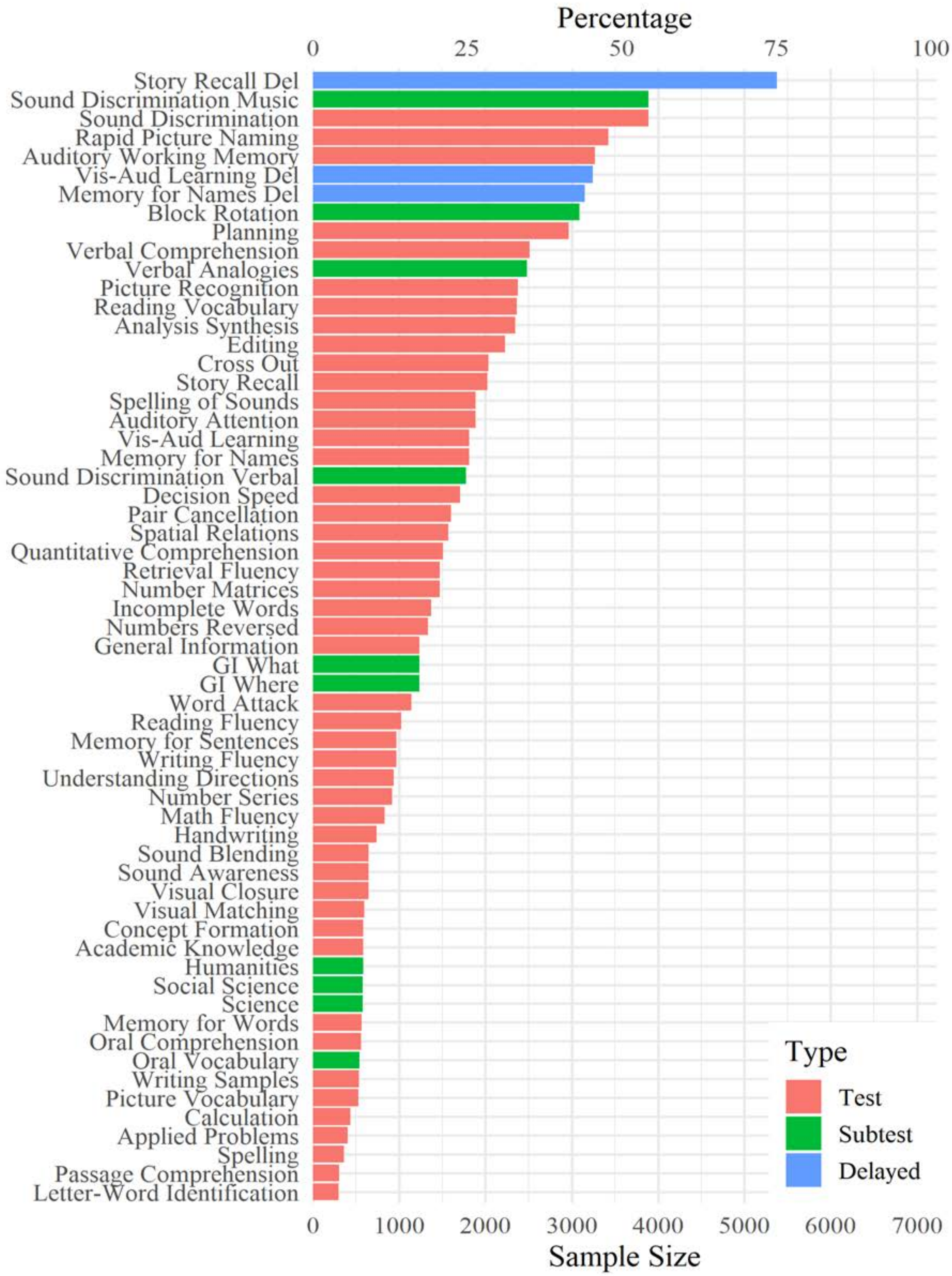
RH 2: The proposed F-CHC model will be the best fitting model for the data in comparison to other chosen models.

The WJ III clinical data set (6000 sets of WJ III Tests of Cognitive Abilities [WJ III COG; Woodcock, McGrew, & Mather, 2001a], WJ III Diagnostic Supplement [WJ III DS; Woodcock, McGrew, Mather & Schrank, 2003] and WJ III Tests of Achievement [WJ III ACH; Woodcock, McGrew, & Mather, 2001b] scores) was the initial data set examined. Initial examination of the data set indicated missing data on some variables/subtests. See Table 1. Variables/subtests with a significant amount of missing data were removed from the analysis (Sound Discrimination-Music, Sound Discrimination-Verbal, Block Rotation, Verbal Analogies, General Information-What and Where, Humanities, Science, and Social Studies, and Oral Vocabulary).

Analyses and Results

Preliminary statistical analysis included descriptive statistics and bivariate correlations. Statistical analyses of the factor structure utilized a combination of exploratory and confirmatory methods using R. The initial exploratory factor analysis resulted in a number of cross loadings between variables. Due to factor impurity these cross loadings were examined for theoretical probability, and where theoretically feasible were retained (or allowed) in the analyses.

Table 1. Analysis of Missing Data

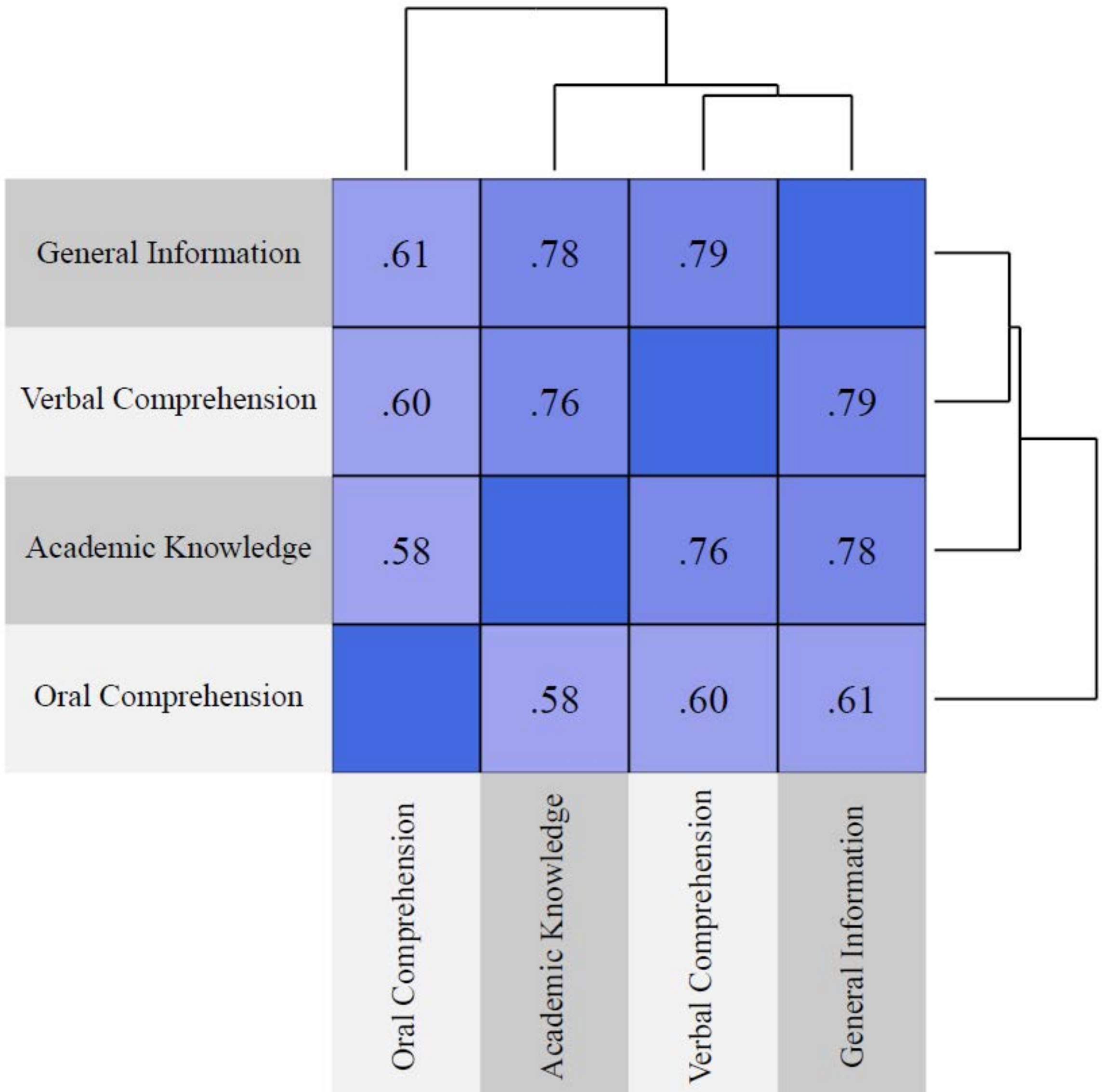


The intent of these analyses was to be truly exploratory, thus EFA was used as a tool to explore multiple subsets of the same data and used in various ways to explore the data. Initially, data were examined by CHC constructs (e.g. *Gc, Gf, Gv, Ga, Gwm, Glr* and *Gs*). Correlation matrices were generated, and parallel analysis was used to generate scree plots that were utilized to examine the number of factors to extract. Parallel analysis is a variant of factor analysis and was used instead of principal components as the factors are expected to be highly correlated. Then exploratory confirmatory factor analyses were utilized to examine various plausible factor structures for each of the broad constructs to provide support for the hypothesized narrow ability groupings. Finally exploratory EFA and CFA were completed to examine the factor structure of the data as a whole to provide support for the hypothesized broad ability groupings. The F-CHC model is hierarchical, but this analysis only examined the proposed narrow and broad abilities, it did not examine the higher order three factor structure of the F-CHC model (e.g. Acquired Knowledge, Thinking Abilities, Cognitive Efficiency).

Comprehension-Knowledge (Gc)

A correlation matrix was generated using the *Gc* identified subtests of General Information, Verbal Comprehension, Academic Knowledge and Oral Comprehension. Although provided in the WJ III standardization data set, it was determined that Verbal Comprehension and Picture Vocabulary could not be used in the same analysis as Picture Vocabulary is a subtest of Verbal Comprehension. An examination of the correlation matrix revealed that the tests are highly related, and that General Information is the subtest that correlates strongest with the other selected *Gc* tasks. See Table 2.

Table 2. Gc Correlation Matrix



In the parallel analysis one factor emerged. However, when the academic subtest Reading Vocabulary was added to the analysis, two clear factors were generated. Consistent with F-CHC, Reading Vocabulary and Verbal Comprehension form a factor that could be termed *Vocabulary* and General Information, Academic Knowledge, and Oral Comprehension form a factor that could be called *General Knowledge*. Adding Reading Vocabulary to the *Gc* factor makes theoretical sense as generally in the research it has only loaded factor analytically with the other reading tasks for the youngest ages (2-5 years) and for all other ages has a primary affiliation with *Gc* with strong secondary loadings on a reading factor for ages 6-8 and 40-100. To evaluate if a stronger *Gc* structure could be developed, Verbal Comprehension and Academic Knowledge were deconstructed into their component parts, Oral Vocabulary, Verbal Analogies, Picture Vocabulary, and Science, Social Studies, and Humanities for the Verbal Comprehension and Academic Knowledge components respectively. The analysis generated support for 1, 2, and 3 factors respectively, with the first factor being extremely strong regardless of the number of contributing components; in other words *Gc* appears to be a robust factor. The three factor solution provides support for a vocabulary of objects factor, a verbal comprehension of abstract concepts factor, and a knowledge factor. The two factor solution offers a distinction between knowledge and verbal ability similar to the F-CHC's proposed model. Both solutions are impacted by cross loadings, which tend to make the factors unstable. Next exploratory confirmatory factor analyses (CFA) were conducted. One, two and three factor models were generated, with the three factor model being the best fitting of three ill-fitting models (CFI 0.984, RMSEA 0.054; CFI 0.984, RMSEA 0.054; and CFI 0.997, RMSEA 0.025 respectively). Ultimately it appears that there is not overall clear separation of *Gc* subtests when using the WJ III standardization sample data.

Fluid Reasoning (CHC-Gf)/ Reasoning (F-CHC-GR)

Four subtests are hypothesized to be *Gf/GR* measures, Concept Formation, Analysis Synthesis, Number Series, and Number Matrices. The parallel analysis suggested 2 clear factors, an inductive factor (Analysis Synthesis, Concept Formation) and a contextual factor (Number Matrices and Number Series). See Tables 3 and 4. The analysis of fluid reasoning tasks was supportive of the F-CHC hypothesized structure of a broad Reasoning factor comprised of two narrow factors, *Contextual Reasoning* and *Inductive/Deductive Reasoning.* (cfi=1.000; rmsea=0.000). This would indicate a near perfect fit for the model. However, with small models that estimate many parameters, intuitions about fit measures start to break down. There is only 1 degree of freedom with this model, meaning that it takes few risks. Many other models also fit perfectly or near perfectly. That said, perfect fit is not guaranteed. For example, if Analysis Synthesis is paired with Number Matrices and Concept Formation is paired with Number Series, the fit is worse: CFI = .98, TLI = .87, RMSEA = 0.16. Even a one-factor model has a CFI of .97.

Table 3. *Gf*/GR Correlation Matrix

	Number Matrices	Number Series	Analysis Synthesis	Concept Formation
Concept Formation	.46	.52	.57	
Analysis Synthesis	.43	.50		.57
Number Series	.58		.50	.52
Number Matrices		.58	.43	.46

One issue to consider for future research is whether or not Number Matrices and Number Series are measuring different narrow abilities, as an argument could be made that Number Matrices is merely a 2-dimensional variant of Number Series, and therefore their correlations as a "factor" are just a method artifact.

Table 4. *Gf*/GR Factor Loadings and Factor Correlations

Factor Loadings

	Inductive	Contextual
Analysis Synthesis	.73	.03
Concept Formation	.71	.07
Number Matrices	.01	.72
Number Series	.12	.70

Factor Correlations

	Inductive	Contextual
Inductive	1.00	.77
Contextual	.77	1.00

Visual Spatial Processing (Gv)

Five subtests are hypothesized to be measures of *Gv*; Visual Closure, Visual Recognition, Block Rotation, Spatial Relations, and Planning. In the F-CHC model, *Gv* is divided into two abilities, *Pictorial Processing* and *Spatial Processing*. In general, *Gv* is a weak factor with parallel analysis suggesting two factors; neither of them very strong but, both of them consistent with the F-CHC hypothesized structure. See Tables 5 and 6. Subsequent EFA analysis suggests a unidimensional and a 2-factor solution model are similar (cfi=0.981, rmsea=0.034; and cfi=0.998, rmsea=0.014 respectively) with the 2-factor solution being slightly better.

Figure 2. Diagram of GR Factor Structure

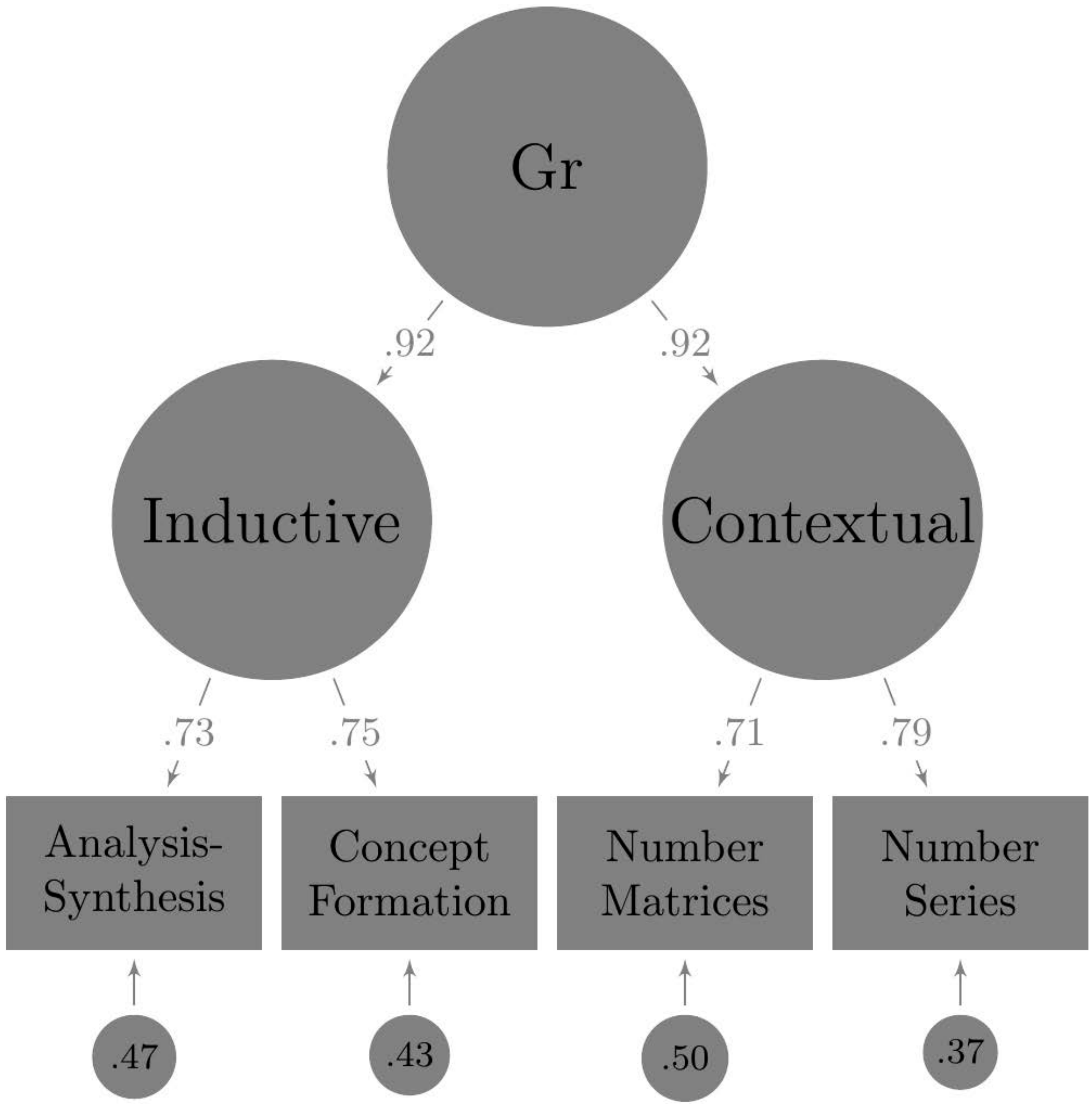


Table 5. *Gv* Correlation Matrix

	Planning	Spatial Relations	Block Rotation	Picture Recognition	Visual Closure
Visual Closure	.11	.20	.16	.15	
Picture Recognition	.12	.19	.16		.15
Block Rotation	.22	.33		.16	.16
Spatial Relations	.27		.33	.19	.20
Planning		.27	.22	.12	.11

Table 6. *Gv* Factor Loadings and Factor Correlations

Factor Loadings

	Spatial	Pictorial
Spatial Relations	.56	.10
Planning	.47	−.05
Block Rotation	.46	.08
Visual Closure	−.02	.43
Picture Recognition	.04	.34

Factor Correlations

	Spatial	Pictorial
Spatial	1.00	.70
Pictorial	.70	1.00

Auditory Processing (Ga)

Five subtests were identified as measures of *Ga* including Incomplete Words, Sound Blending, Auditory Attention, Sound Discrimination-Verbal, and Sound Discrimination-Music. The F-CHC model suggests that *Ga* can be distilled into two factors, *Sound Discrimination* and *Phonetics*. The correlation matrix suggested an odd structure for the Ga factor (See Table 7). Sound Discrimination-Music was missing a lot of data and it correlated with all the other tasks. When entered into the EFA numerous Heywood cases were created. The only preliminary factor structure that sort of made sense statistically was a 3-factor solution where Auditory Attention formed a single factor, Sound Discrimination-Verbal and Sound Discrimination-Music formed a factor, and Incomplete Words and Sound Blending formed a factor. While this structure is consistent with CHC theory in that it predicts factors thought to measure phonological functions, discrimination skills, and resistance to distortion abilities, it is compromised by Sound Discrimination-Music loading equally on the factors, and in particular its association with phonological measures, which makes no theoretical sense. In subsequent analyses Sound Discrimination-Music was removed, however, this did not result in improvement in the structure of *Ga* as measured by these WJ III tasks. Many possibilities could be postulated, but the primary take-away from this analysis is there are problems using the WJ III tasks hypothesized to measure *Ga* to achieve a good understanding of the construct of *Ga*. Either they do not measure *Ga* as thought, or *Ga* is a very misunderstood and rather vague factor.

Table 7. *Ga* Correlation Matrix

	Sound Discrimination Music	Sound Discrimination Verbal	Auditory Attention	Sound Blending	Incomplete Words
Incomplete Words	.61	.25	.29	.41	
Sound Blending	.63	.33	.36		.41
Auditory Attention	.54	.22		.36	.29
Sound Discrimination Verbal	.78		.22	.33	.25
Sound Discrimination Music		.78	.54	.63	.61

Processing Speed (CHC-Gs)/Cognitive Processing Speed (F-CHC-Gs)

Six subtests, Retrieval Fluency, Rapid Picture Naming, Visual Matching, Pair Cancellation, Cross Out, and Decision Speed were included in the analysis of the processing speed factor. One, two, three and four factor solutions were examined. The two-factor solution proved to be the best fitting (See Tables 8 and 9). In the two factor model (cfi=0.954; rmsea=0.129), Pair Cancellation, Visual Matching, Cross Out, and Decision Speed form a factor that F-CHC labels *Perceptual Speed*; whereas Retrieval Fluency and Rapid Picture Naming make up a second factor that F-CHC labels *Thinking Speed*.

Short-Term Memory/Short-Term Working Memory/Long Term Storage and Retrieval (CHC-Gsm/Gwm and Glr)/Conscious Memory and Learning and Memory (F-CHC-Gcm and Glm)

Conceptualization of memory skills has been problematic within CHC theory since the beginning. CHC has taken a narrow view of memory skills, evaluating primarily short-term memory capacity, working memory, and long-term storage and retrieval (a combination of associative memory and memory retrieval skills). The construct of memory is significantly more complex than the aspects of memory measured by various tasks and the portrayal of memory skills within CHC theory. In F-CHC theory short-term immediate memory span and working memory are hypothesized to be an aspect of cognitive efficiency and have been labeled *Conscious Memory*. The immediate associative recall and retrieval aspects of memory are considered to be more complex and part of an individual’s active thinking processes, and in the F-CHC model carry the label of *Learning and Memory* (*Glm*).

The analysis included Visual Auditory Learning, Visual Auditory Learning-Delayed, Memory for Names, Memory for Names-Delayed, Story Recall, Story Recall-Delayed, Understanding Directions, Auditory Working Memory, Numbers Reversed, Memory for Sentences, and Memory for Words. There were a number of issues with the delayed versions of the tasks (missing data, Heywood cases, method artifacts) and these tasks were removed from the analysis. Four clear factors with a second order structure were extracted (See Tables 10 and 11). The four factor model exhibited good fit (cfi=0.980; rmsea=0.055) and as modeled supports the F-CHC 2-factors for memory (*Gcm* and *Glm*) (See Figure 3). Although there is good evidence for the F-CHC modeling of memory, there is considerable need for further exploration.

Table 8. *Gs* Correlation Matrix

	Decision Speed	Cross Out	Pair Cancellation	Visual Matching	Rapid Picture Naming	Retrieval Fluency
Retrieval Fluency	.36	.33	.33	.36	.42	
Rapid Picture Naming	.33	.34	.37	.35		.42
Visual Matching	.53	.62	.77		.35	.36
Pair Cancellation	.64	.58		.77	.37	.33
Cross Out	.52		.58	.62	.34	.33
Decision Speed		.52	.64	.53	.33	.36

Table 9. *Gs* Factor Loadings and Factor Correlations

Factor Loadings

	Perceptual Speed	Thinking Speed
Pair Cancellation	.96	−.10
Visual Matching	.86	−.03
Cross Out	.65	.08
Decision Speed	.60	.13
Retrieval Fluency	−.08	.78
Rapid Picture Naming	.10	.52

Factor Correlations

	Perceptual Speed	Thinking Speed
Perceptual Speed	1.00	.65
Thinking Speed	.65	1.00

Table 10. *CHC-Gsm/Gwm and Glr/F-CHC-Gcm and Glm*

	Memory for Words	Memory for Sentences	Numbers Reversed	Auditory Working Memory	Understanding Directions	Story Recall	Memory for Names	Memory for Names Del	Vis−Aud Learning	Vis−Aud Learning Del
Vis−Aud Learning Del	.24	.30	.32	.33	.42	.36	.48	.50	.70	
Vis−Aud Learning	.31	.39	.39	.36	.45	.40	.56	.48		.70
Memory for Names Del	.23	.26	.25	.26	.29	.30	.74		.48	.50
Memory for Names	.24	.30	.28	.27	.33	.34		.74	.56	.48
Story Recall	.24	.41	.27	.35	.43		.34	.30	.40	.36
Understanding Directions	.38	.42	.44	.45		.43	.33	.29	.45	.42
Auditory Working Memory	.42	.43	.44		.45	.35	.27	.26	.36	.33
Numbers Reversed	.41	.39		.44	.44	.27	.28	.25	.39	.32
Memory for Sentences	.54		.39	.43	.42	.41	.30	.26	.39	.30
Memory for Words		.54	.41	.42	.38	.24	.24	.23	.31	.24

Table 11. Factor Structure for Gcm and Glm

First−Order Factors

	Memory Span	Executive Control	Associative Memory	Meaningful Memory
Memory for Words	.71	.15	−.01	−.14
Memory for Sentences	.66	−.05	.03	.19
Numbers Reversed	.06	.67	.05	−.12
Auditory Working Memory	.14	.54	−.06	.09
Understanding Directions	−.03	.53	.05	.22
Vis−Aud Learning	−.03	.13	.76	−.03
Memory for Names	.03	−.07	.69	.04
Story Recall	−.02	.00	.02	.77

Second−Order Factors

	Memory Span	Executive Control	Associative Memory	Meaningful Memory
Long−Term Memory (Glm)	.21	−.08	.67	.92
Conscious Memory (Gcm)	.58	.90	.27	−.07

EFA with all Constructs

The next step in shaping the F-CHC model was conducting EFA with all of the constructs. For this, all of the academic subtests were removed with the exception of the knowledge tests and Reading Vocabulary. Additionally, all of the delayed memory tasks and Sound Discrimination-Music were removed. The correlation matrices and parallel analysis suggested 9 factors. (See Table 12). Solutions for extracting more than nine factors tended not to converge and were problematic (i.e. Heyward cases). Using exploratory CFA a variety of models were evaluated from a one factor model to an eight factor model.

The one-factor (g) model (cfi=0.690; rmsea=0.093) was not expected to fit well, although in actuality it was not too bad. The two-factor model (g + *Gc*) was slightly better (cfi=0.748; rmsea=0.084), as was the three factor model of g + *Gc* + *Gr* (cfi=0.758; rmsea 0.082). Incremental model increases resulted in slightly better fits with each additional factor. The four factor model of g + *Gc* + *Gr* + *Gv* results in cfi=0.761 and rmsea=0.082; the five factor model of g + *Gc* + *Gr* + *Gv* + *Ga* gave cfi= 0.765 and rmsea

= 0.081; the six factor model of g + *Gc* + *Gr* + *Gv* + *Ga* + *Gcm* resulted in a cfi =0.774 and rmsea = 0.080; the seven factor model of g + *Gc* + *Gr* + *Gv* + *Ga* + *Gcm* +*Glm* provided a cfi = 0.786 and rmsea = 0.078; adding *Gs* to model for eight factors (g + *Gc* + *Gr* + *Gv* + *Ga* + *Gcm* + *Glm* + *Gs*) resulted in cfi = 0.878 and an rmsea= 0.059. The nine-factor model suggests that *Gr* should be separated into its two components of Inductive/Deductive Reasoning and Contextual Reasoning and that these be treated as equal factors (cfi= 0.882; rmsea =0,058). Various other ways of splitting the data, such as splitting *Gc Gv, Gcm, Glm* or *Gs* did not result in any incremental improvements in the factor structure. See Table 13.

Figure 3. Diagram of F-CHC Memory Factors

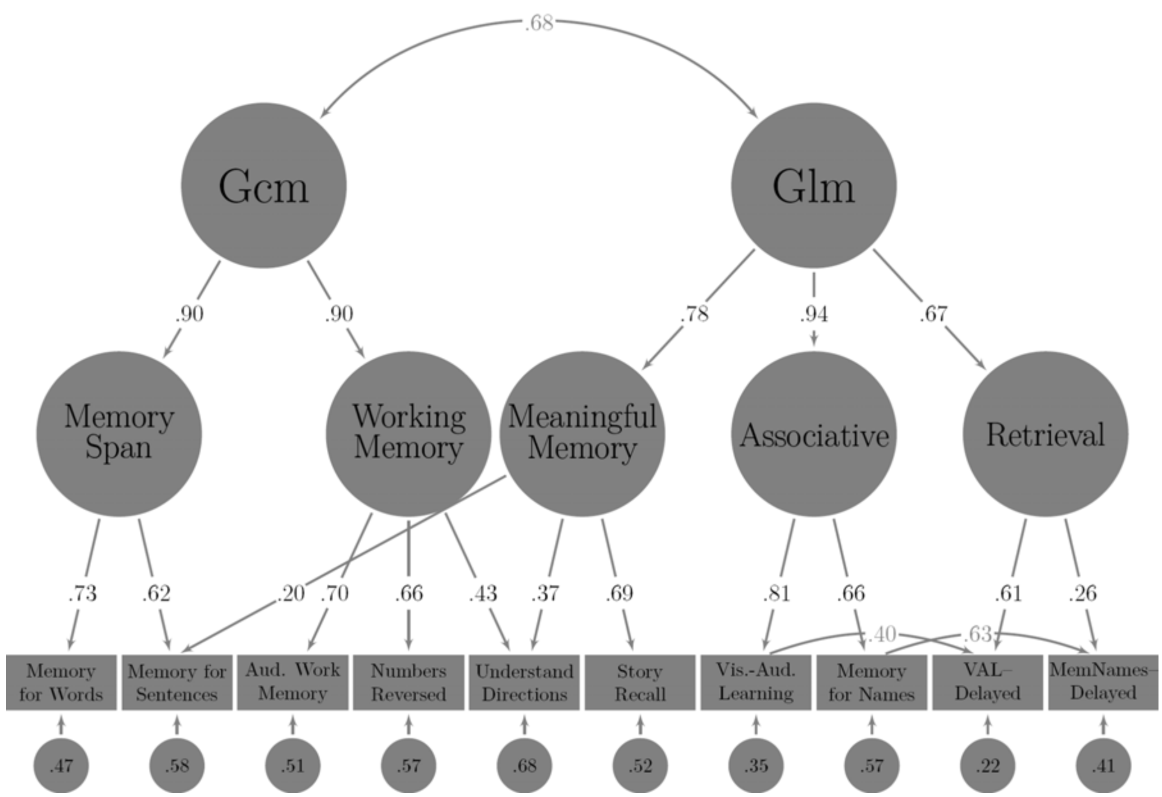


Table 12. Correlation Matrix for EFA of All Constructs

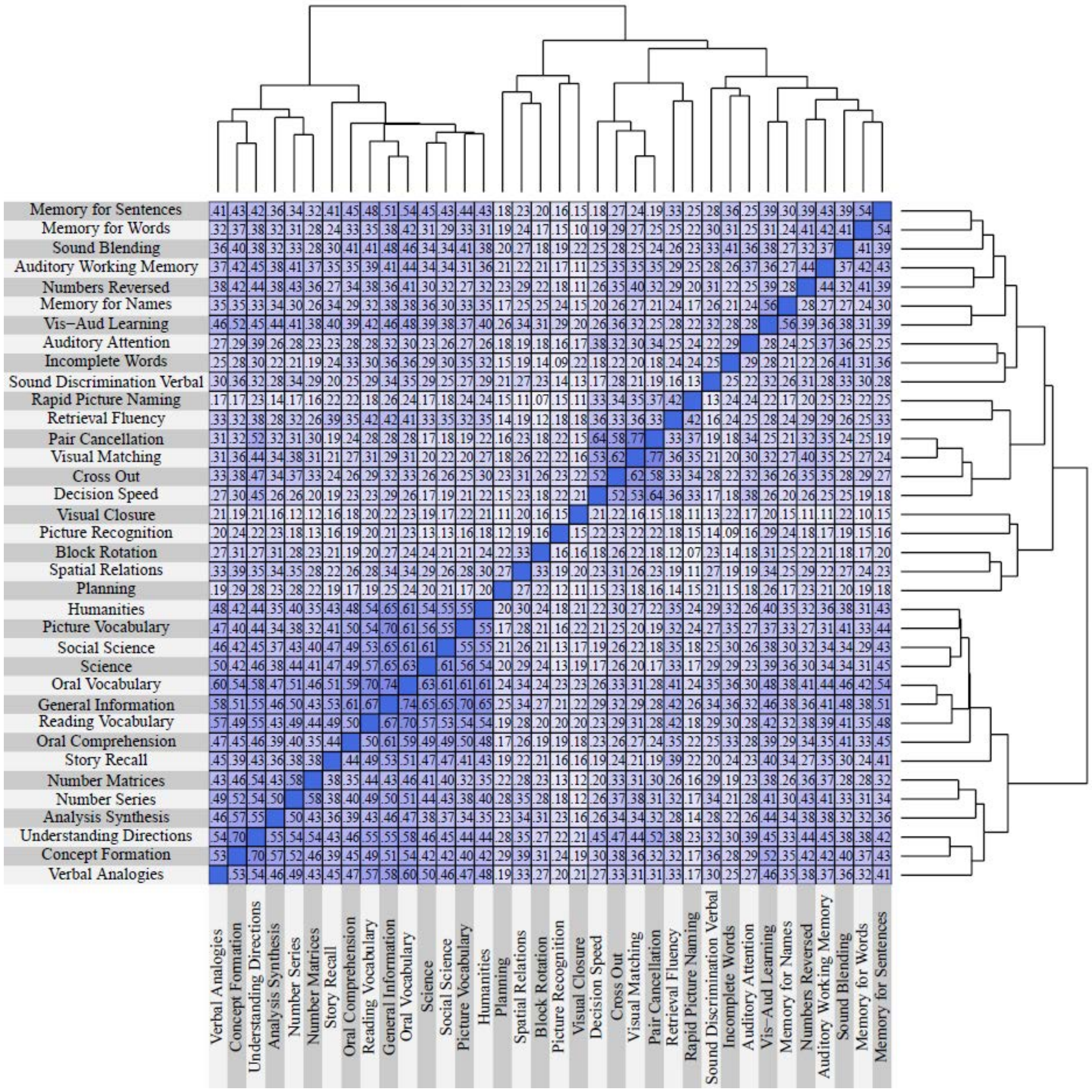


Table 13. Comprehensive Factor Loadings and Factor Correlations for All Constructs

Factor Loadings

	Gc	Gs Perceptual	Gcm	Gr Induct	Glm	Gv	Ga	Gr Context	Gs Thinking
General Information	.90	.05	−.02	−.04	−.03	.02	.04	.01	−.02
Science	.82	−.03	−.05	−.12	.02	.07	−.05	.12	−.02
Picture Vocabulary	.80	.02	.01	−.08	−.01	.02	.10	−.10	−.05
Social Science	.78	−.02	−.07	−.11	−.03	.03	−.00	.15	.04
Oral Vocabulary	.73	.03	.14	.10	−.01	−.03	−.03	.01	−.03
Humanities	.72	.05	.01	−.15	.05	.08	−.01	−.00	.02
Reading Vocabulary	.67	.05	.06	.18	−.02	−.13	−.05	.07	−.01
Oral Comprehension	.52	−.01	.10	.13	−.01	−.08	.08	−.01	.02
Verbal Analogies	.45	.07	.00	.25	.09	.01	−.06	.08	−.07
Story Recall	.40	−.14	−.09	.10	.19	−.10	−.01	.16	.23
Pair Cancellation	.05	.99	.01	.06	−.05	−.18	.02	.02	−.08
Visual Matching	.06	.86	.12	−.13	.07	.01	−.16	.05	.01
Decision Speed	−.05	.58	−.15	.14	−.05	.00	.20	−.06	.12
Cross Out	−.02	.54	.04	−.06	.00	.24	−.00	.07	.08
Memory for Words	−.01	.03	.79	.04	−.09	.03	.01	−.11	−.00
Memory for Sentences	.25	−.10	.61	.08	.01	−.07	−.05	−.12	.12
Numbers Reversed	−.04	.11	.39	.05	.06	.11	−.08	.17	.05
Auditory Working Memory	−.00	.07	.30	.05	.06	−.11	.21	.24	.03
Concept Formation	−.03	−.09	.13	.66	−.01	.16	.01	.12	−.04
Understanding Directions	.11	.16	−.01	.66	−.16	−.04	.13	.22	−.04
Analysis Synthesis	.05	−.00	.05	.42	.07	.15	−.05	.19	−.05
Memory for Names	.12	.01	−.07	−.15	.79	−.04	.03	−.03	−.05
Vis−Aud Learning	−.00	−.08	.00	.04	.73	.07	.07	.03	−.02
Picture Recognition	−.06	.09	.02	.11	.26	.09	−.03	−.12	.05
Spatial Relations	.05	.01	.04	.07	−.08	.65	−.12	.01	−.01
Block Rotation	−.00	.01	−.03	.01	.11	.48	−.05	.06	−.06
Planning	−.08	−.07	.01	−.01	−.04	.39	.06	.17	.08
Sound Discrimination Verbal	.05	.00	.16	−.05	.05	.27	.15	.11	−.11
Visual Closure	.11	.03	−.11	.07	−.00	.23	.14	−.17	.04
Auditory Attention	−.08	.11	−.11	.05	.06	−.12	.63	.16	−.00
Sound Blending	.11	−.05	.22	.03	.03	.01	.49	−.05	−.08
Incomplete Words	.13	−.07	.18	−.04	−.04	.04	.41	−.09	.04
Number Series	.20	.03	−.09	.10	−.06	.21	.00	.56	.03
Number Matrices	.20	.02	−.10	.14	−.04	.08	.03	.54	−.00
Retrieval Fluency	.14	−.01	.00	.08	−.07	−.01	−.10	.04	.70
Rapid Picture Naming	−.04	.16	.08	−.20	.01	−.01	.10	−.01	.53

Factor Correlations

	Gc	Gs Perceptual	Gcm	Gr Induct	Glm	Gv	Ga	Gr Context	Gs Thinking
Gc	1.00	.33	.59	.68	.62	.58	.61	.41	.53
Gs Perceptual	.33	1.00	.37	.54	.47	.50	.50	.32	.56
Gcm	.59	.37	1.00	.50	.56	.48	.58	.55	.41
Gr Induct	.68	.54	.50	1.00	.68	.63	.53	.42	.48
Glm	.62	.47	.56	.68	1.00	.66	.51	.42	.48
Gv	.58	.50	.48	.63	.66	1.00	.61	.33	.37
Ga	.61	.50	.58	.53	.51	.61	1.00	.21	.55
Gr Context	.41	.32	.55	.42	.42	.33	.21	1.00	.21
Gs Thinking	.53	.56	.41	.48	.48	.37	.55	.21	1.00

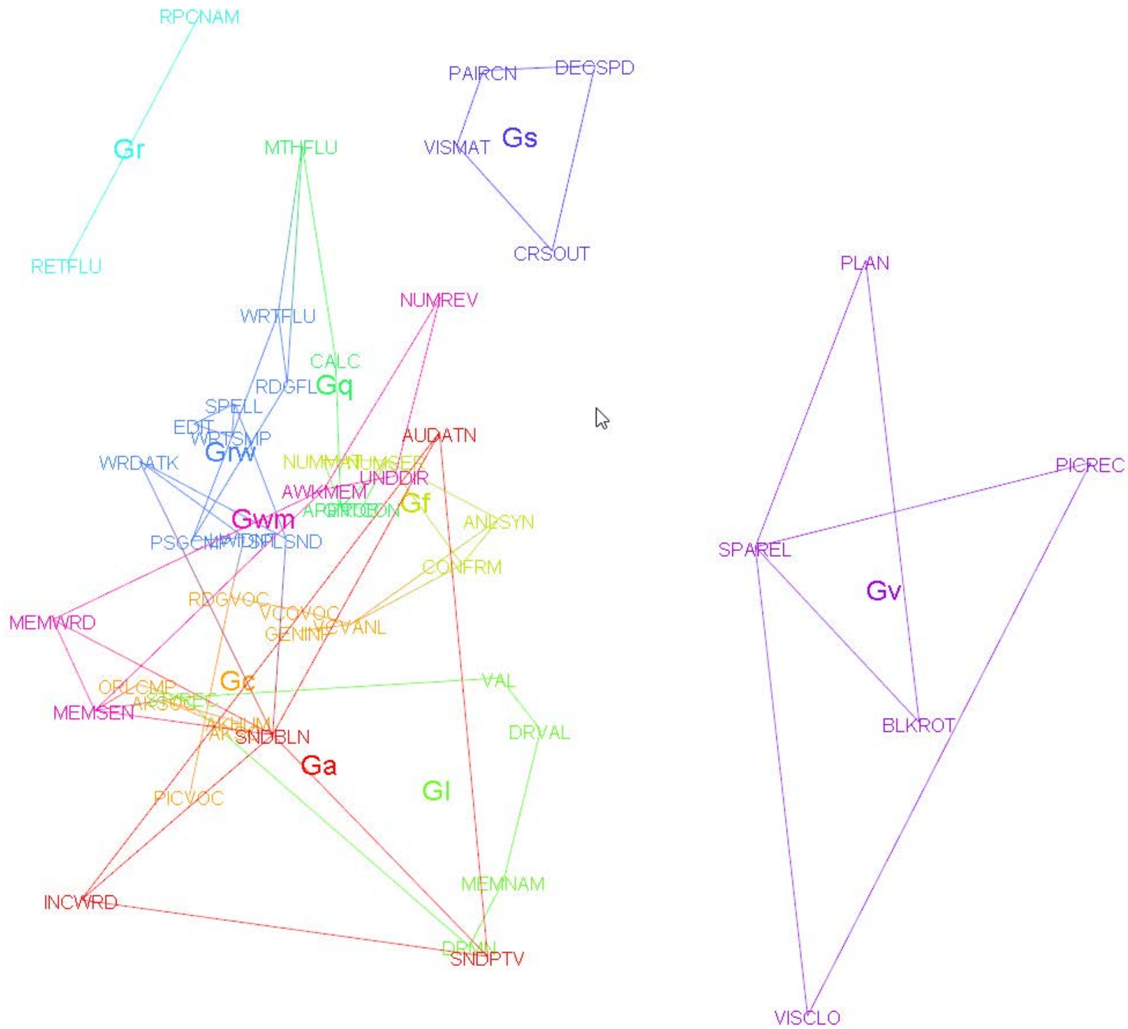
Finally, multidimensional scaling (MDS) was used to further examine the identified factor structure. MDS is a way to visualize the level of similarity among individual cases within a data set. It is used to translate information about the pairwise distance among a set of n objects or individuals into a configuration of n points mapped into 3-dimensional Cartesian space. MDS is a flexible form of factor analysis that is based on proximity. In other words, correlated constructs tend to be close in 3-dimensional space whereas uncorrelated or less correlated constructs tend to be far apart. The MDS was supportive of three clear dimensions consistent with the F-CHC proposed factor structure. See Figure 4.

Discussion, Limitations and Future Directions

Generally, the results of the analyses provide support for the validity of the broad abilities and narrow groupings posited by the F-CHC model. This is not surprising as the F-CHC model closely resembles the original CHC factor structure on which it is based. Additionally the WJ III series of instruments were explicitly developed to reflect the CHC model, so it is not unexpected that the results would resemble the identified factor structure of the WJ III and the CHC model upon which it is based. There are some weak or problem factors, primarily with *Gc*, the memory factors, and *Ga*. Both the memory and auditory processing factors have been identified in the literature as being more complex and difficult to measure than is conceptualized by CHC theory and measured by the WJ III. Still, the proposed structure of the F-CHC model is solidly supported by the current data. The proposed research question and hypotheses for this study were generally supported.

The current analysis is limited by the use of the WJ III data set. Other data sets from the Woodcock-Johnson series or other measures of cognitive functioning may not support the proposed F-CHC structure. Subsequent research should evaluate the standardization data sets of the WJ-R, WJ IV and possible clinical data sets in order to more thoroughly investigate the F-CHC model.

Figure 4. Multidimensional Scaling Diagram



Additionally, obtaining pure factors of a particular construct is problematic as many of the cognitive skills and abilities being measured are complex groupings of multiple skills or narrow abilities, all or most of which are required for adequate performance on a specific construct. The F-CHC model should be evaluated on the results of this and companion research to determine adequate support for its constructs. Furthermore, assiduous consideration of these results and others should be used to carefully examine the constructs and modify the constructs or the model as appropriate.

References

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

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

Cattell, R. B. (1963). Theory of fluid and crystallized intelligence: A critical experiment. *Journal of Educational Psychology, 54,* 1-22. Doi:10.1037/h0046743.

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

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

Horn, J. L. (1965) *Fluid and crystallized intelligence: A factor analytic study of structure among primary mental abilities.* Unpublished doctoral dissertation. University of Illinois at Urbana-Champaign (AAT 6507113).

Horn, J. L. & Cattell, R. B. (1966). Refinement and test of the theory of fluid and crystallized general intelligence. *Journal of Educational Psychology, 57*, 253-270. Doi: 10.1037/h0023816.

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

Keith, T. Z., & Reynolds, M. R. (2010). Cattell-Horn-Carroll abilities and cognitive tests: What we've learned from 20 years of research. *Psychology in the Schools, 47*, 635-650. Doi: 10.1002/pits.20496.

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

McGrew, K. S., LaForte, E. M., & Schrank, F. A. (2014). *Woodcock Johnson IV technical manual.* Itasca, IL: Riverside.

Miller, D. C. (2013). *Essentials of school neuropsychological assessment—Second Edition*. Hoboken, NJ: Wiley.

Schneider, W. J., & McGrew, K. S., (2018). The Cattell-Horn-Carroll theory of cognitive abilities. In D. P. Flanagan & E. M. McDonough (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues. 4th Edition*. (pp. 73-163). New York, NY: Guilford.

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

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001a). *Woodcock-Johnson III Tests of Cognitive Abilities*. Itasca, IL: Riverside.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001b, 2007b). *Woodcock-Johnson III Tests of Achievement*. Itasca, IL: Riverside.

Woodcock, R. W., McGrew, K. S., Mather, N., & Schrank, F. A. (2003). *Woodcock-Johnson III Diagnostic Supplement to the Tests of Cognitive Abilities*. Itasca, IL: Riverside.

Woodcock, R., Miller, D., Maricle, D. & McGill, R. (Eds). (2017) *Evidenced Based Selective Assessment for Academic Disorders.* Middleton, MD: School Neuropsych Press.