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BAYLOR UNIVERSITY
SCHOOL OF EDUCATION

Are we Over-*Interpreting Students' Performance on Tests of Intelligence?*

A Re-Analysis of the Foundations of CHC Theory

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Agenda

- Intro to the Cattell-Horn-Carroll (CHC) theory and its foundations
- Need for Study
- Our method and results
- Theoretical implications
- Practical implications

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Introduction

CHC Theory and its Foundations

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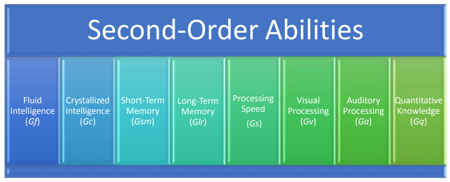
Cattell-Horn *Gf-Gc* Theory



Intelligence represents effects and interactions of numerous abilities working in concert. *Gf* and *Gc* viewed as more general abilities that support the others, *g* is not in the model.
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Carroll's Three-Stratum Theory

- Strata distinguished by generality (breadth) and abstraction of abilities
- Direct hierarchical (bifactor) structure (Beaujean, 2015)
  - *g* and group factors have direct effects on measured abilities
  - *g* and group factors are orthogonal
- Provides the corpus of evidence for CHC theory
  - Frequently cited as empirical basis for interpreting lower strata abilities

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Cattell-Horn-Carroll (CHC) Theory

- Integration of *Gf-Gc* and Three-Stratum theories
- 3 strata, more broad abilities than Three-Stratum theory

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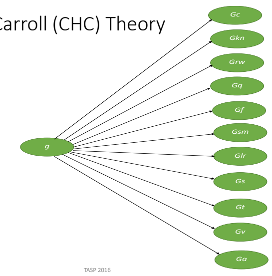
Cattell-Horn-Carroll (CHC) Theory



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Cattell-Horn-Carroll (CHC) Theory

- Higher-order, mediational structure in which g has indirect effects on measured abilities via second-order abilities
  - Emphasis on lower strata, interpretation of *g* is optional based on theoretical orientation (Schneider & McGrew, 2012)

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Cattell-Horn-Carroll (CHC) Theory

- Dominant theory guiding the contemporary, applied assessment of intelligence
    - WJ-IV
    - DAS-2
    - KABC-II
    - SB-5
    - WISC-V

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Need for Study

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Limitations with Carroll's Analyses

- Relied on exploratory factor analysis (EFA) with Schmid-Leiman (SL) transformations, which did not allow for true bi-factor rotations
  - "SL can only be accurate when certain, highly unlikely, conditions exist (perfect cluster structure, proportionality) and the sample is large enough so that the correlation matrix reflects the population" (Mansolf & Reise, 2016, p. 17)
    - Condition 1: Perfect item structure (items load exclusively on *g* and a single group factor)
    - Condition 2: Proportionality (ratio of general and group factor loadings is the same for all mental tasks associated with a group factor)

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Limitations with Carroll's Analyses

- Carroll compared EFA and confirmatory factor analysis (CFA) results for the Gustaffson (1984) and Palmer, Macleod, Hunt, and Davidson (1985) studies
  - Results differed in important ways
  - Carroll argued that the two methods (EFA & CFA) should be used in combination (Carroll, 1995).

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Limitations with Carroll's Analyses

- Carroll's placement of abilities into Stratum I or Stratum II was largely a qualitative decision based on re-analysis of 467 studies
  - No single sample has been administered a sufficient range of mental tasks to allow for testing of a model containing all purported abilities
  - Carroll only identified >2 second-order factors in 18 data sets
    - Vast majority (16) of these studies had 3 second-order factors
    - Maximum number of second-order factors identified = 5

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Limitations with Carroll's Analyses

- According to Carroll (1993),"Many factors remain inadequately specified, and many aspects of the three-stratum theory need to be tested and refined" (p. 688).

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Research Questions

1. Did Carroll over-factor the datasets he analyzed and identify factors that are non-replicable or explain trivial percentages of common factor covariance?
2. To what extent are identified factors sufficiently reliable for clinical interpretation?

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Method and Results

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Selection of Data Sets

- Focused on 10 studies from which Carroll extracted the most second-order factors
  - Selected to maximize the possibility of identifying Stratum II abilities

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Analysis-Study A

- Re-analysis with two methods
  - Jennrich and Bentler’s EFA bi-factor rotation
  - Higher-order EFA with orthogonal transformation
- Comparisons
  - Jennrich and Bentler’s criterion for bi-factor structure, $Q(\boldsymbol{\Lambda})$. Smaller values indicate better bi-factor structure (i.e., loadings on g and 1 other factor).
  - Model-based reliability estimates for each factor
    - Coefficient omega (ω)
    - Omega hierarchical (ωh)

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Results-Study A

Study	$\Delta Q(\Lambda)^{\dagger}$	ω		ω_h	
		S-L	BF	S-L	BF
Christal (1958)	-.07	.93	.94	.63	.75
Fogarty (1987)	+.02	.95	.96	.78	.90
Gustafsson (1984)	-.89	.95	.95	.73	.87
Hakstian & Cattell (1974)	-.16	.92	.93	.74	.90
Hakstian & Cattell (1978)	-.16	.81	.87	.47	.82
Horn (1965)	-.59	.94	.94	.67	.90
Horn & Stankov (1982)	-.07	.89	.90	.69	.87
Sung & Dawis (1987)	+.16	.84	.91	.64	.83
Thurstone & Thurstone (1941)	-3.76	.97	.97	.63	.91
Undheim (1981)	-.11	.94	.95	.77	.92

Notes. † = Change in $Q(\Lambda)$ when using an analytic bi-factor rotation rather than the Schmid-Leiman transformation. ω = coefficient omega. ω_h = omega hierarchical. S-L = Schmid-Leiman transformation. BF = bi-factor rotation.

- $Q(\boldsymbol{\Lambda})$ estimates were typically lower when using the bi-factor rotation.
- ω_h was consistently higher for bi-factor models (average for S-L transformation:.68; average for bi-factor rotation: .87).

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Results-Study A (cont.)

- The number of well-defined group factors using a bi-factor model typically < higher-order model.
- Group factors more consistent with Stratum I than Stratum II abilities
  - Typically, only two to three tests of similar content had moderate to strong loadings on each group factor.

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Analysis-Study B

- Analyzed 5 of 10 previously selected data sets
  - Only data sets for which means and SDs were reported
  - Model for Sung and Dawis (1987) did not converge
- CFA with bi-factor models
  - Initial models based on Carroll's EFA results
  - The Christal (1958) model was bi-factor with correlated unique variances for group factors
    - Correlated unique variances appear to be consistent with Stratum II abilities
    - Akaike weights were used for model comparisons

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Results-Study B

- Christal (1958)
  - Identified 9 of 12 factors identified by Carroll (1993)
    - Associative memory, associative memory (color), general information, numerical facility, and motivation (Carroll viewed as Stratum I abilities)
    - Broad visual perception specified as a factor, broad memory ability and crystallized intelligence are represented by correlated group factors (Carroll viewed as Stratum II abilities)
    - *g* (Carroll viewed as Stratum III)

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Results-Study B

- Fogarty (1987)
  - Identified 7 of 9 factors identified by Carroll (1993)
    - Spelling ability and time sharing (Carroll viewed as Stratum I abilities)
    - Broad auditory function, broad visual perception, crystallized intelligence, and fluid intelligence (Carroll viewed as Stratum II abilities)
    - *g* (Carroll viewed as Stratum III)

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Results-Study B (cont.)

- Hakstian & Cattell(1978)
  - Identified 6 of 8 factors identified by Carroll (1993)
    - Broad memory ability, broad retrieval ability, broad visual perception, crystallized intelligence, and fluid intelligence (Carroll viewed as Stratum II abilities)
    - *g* (Carroll viewed as Stratum III)

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Results-Study B (cont.)

- Undheim(1981)
  - Identified 5 of 6 factors identified by Carroll (1993)
    - Broad speediness, broad visual perception, crystallized intelligence, and fluid intelligence (Carroll viewed as Stratum II abilities)
    - *g* (Carroll viewed as Stratum III)

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Results-Study B

		g	*Ga*	*Gc*	*Gf*	*Glr*	*Gs*	*Gv*	*Gy*	KO	MA	MA-C	MO	N	SG	TS
	ω	ω_h	ω_s	ω_s	ω_s	ω_s	ω_s	ω_s	ω_s	ω_s	ω_s	ω_s	ω_s	ω_s	ω_s	ω_s
Christal (1958)	.93	.91						.23		.20	.65	.12	.13	.17		
Fogarty (1987)	.96	.96	.41	.13	.13			.19							.19	.27
Hakstian & Cattell (1978)	.85	.83		.06	.17	.17	.10	.07	.05							
Undheim (1981)	.94	.93			.16	.40	.44	.19								

Notes. ***g*** **= general intelligence,** ***Ga*** **= broad auditory function,** ***Gy*** **= broad memory ability,** ***Glr*** **= broad retrieval ability,** ***Gv*** **= broad visual perception,** ***Gc*** **= crystallized intelligence,** ***Gf*** **= fluid intelligence,** ***Gs*** **= broad speediness, KO = general information, MA = associative memory, MO = motivation factor, MA-C = associative memory-color, N = numerical facility, SG = spelling ability, TS = time sharing.**

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Results-Study B (cont.)

- Similar to results from Study A
  - The number of well-defined group factors using a bi-factor model typically < higher-order model.
  - Typically, only two to three tests of similar content had moderate to strong loadings on each group factor.
    - Exceptions are associative memory in Christal (1958) and broad auditory function in Fogarty (1987)
  - Estimates of reliability
    - Average for *g* (ω_h) = .91
    - Average for unique variance for Stratum II abilities (ω_s) = .21
    - Average for unique variance for Stratum I abilities (ω_s) = .25

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Theoretical Implications

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Over-factoring

- Reliance on EFA with SL transformation led to unnecessarily complex theory
  - Some Stratum II and Stratum I abilities likely of little theoretical and/or practical import
  - Most mental tasks examined were found to be good measures of *g*
    - After accounting for *g* there is typically little reliable variance uniquely attributable to group factors

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Future Directions

- Results support using bi-factor models rather than higher-order models
  - Guards against over-factoring
- Need for additional investigation regarding the structure of intelligence
- Need for additional investigation to determine what the lower strata abilities explain
  - Theory or taxonomy?
    - Former requires evidence of explaining one or more phenomena

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Practical Implications

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Carroll's (1993) Goal

- Identify and interpret the abilities that comprise intelligence "without regard" for their relative importance or usefulness (p. 693).

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Current Practice

- Interpretation of Stratum II abilities are emphasized in most test manuals
- Interpretations of first- and second-stratum abilities are emphasized in the cross-battery assessment approach (Flanagan, Alfonso, & Ortiz, 2012).
- Results from our analyses do not support citation of Carroll's (1993) work as empirical basis for interpreting lower strata abilities

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Acting on Evidence

- With respect to the prediction of educational outcomes, many studies suggest limited incremental validity (beyond *g*) for lower strata abilities
- Absence of evidence of instructional utility for patterns of strengths and weaknesses in lower strata abilities (Miciak et al., 2016)
- Our results provide further evidence against the de-emphasis of *g* in lieu of abilities at lower-strata.

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Acting on Evidence

- Brain-behavior isomorphism fallacy (Fletcher & Taylor, 1984)
  - Unclear if performance with behavioral tests reflects neurological dysfunction
  - Cognitive test scores are products of mental activity that reflect individual differences
    - We can make reliable inferences about general ability but not about specific cognitive processes
  - Performance deficits may arise from a variety of sources other than neurological dysfunction

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Acting on Evidence

- PSW models
  - Burden for evidenced supporting PSW methods should fall upon those advocating their use (Kranzler et al., 2016)
  - Simulation studies demonstrate limited utility with single indicators of abilities and only modest improvement when using multiple indicators (e.g., Miciak et al., 2014)
  - Difficult to reliably assess strengths and weaknesses due to insufficient unique, reliable variance compounded with imperfect measurement
    - Creates signal to noise problem

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Spot the Difference Analogy: Limited variance with low reliability

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Spot the Difference Analogy: Limited variance with high reliability

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Future Directions

- Test design considerations
  - Possible goal: Maximize variance for *g* (focus on interpretation of *g*)
  - Possible goal: Include tests that maximize unique (non-*g*) variance for group factors
    - Does this unique variance for group factors have utility?
      - Incremental validity for prediction
      - Instructional utility
- Construct scores (Benson et al., 2016)
  - Allows for separation of *g* variance from residual variance for group factors

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Questions

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