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

Introduction
CHC Theory and its Foundations
Cattell-Horn Gf-Gc Theory

Second-Order Abilities

Fluid Intelligence (Gf)
Crystallized Intelligence (Gc)
Short-Term Memory (Gsm)
Long-Term Memory (Glr)
Processing Speed (Gs)
Visual Processing (Gv)
Auditory Processing (Ga)
Quantitative Knowledge (Gq)

Intelligence represents effects and interactions of numerous abilities working in concert. Gf and Gc viewed as more general abilities that support the others, and g is not in the model.

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

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)
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.
• Most samples (54) of these studies had 3 second-order factors.
• Maximum number of second-order factors identified = 5.

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).

Research Questions

1. Did Carroll over-factor the datasets he analysed 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?
Method and Results

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

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(1): 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)
Results - Study A

• Q(\cdot) estimates were typically lower when using the bi-factor rotation.
• \(\omega_h\) was consistently higher for bi-factor models (average for S-L transformation: .68; average for bi-factor rotation: .87).

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.

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.
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)

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)

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)
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)

Results—Study B

- Similar to results from Study A
- The number of well-defined group factors using a bifactor model typically < higher-order model.
- Typically, only two to three tests of similar content had moderate to strong loadings on each group factor.
- Estimates of reliability:
  - Average for $\omega_g = .91$
  - Average for unique variance for Stratum I abilities $\omega_s = .25$
  - Average for unique variance for Stratum II abilities $\omega_s = .21$
Theoretical Implications

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 attributable to group factors

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?
  - Further requires evidence of explaining one or more phenomena
Practical Implications

Carroll’s (1993) Goal

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

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
- Compute unique variance for group factors from validity
- Incremental validity for prediction
- Instructional utility
- Construct scores (Bemiss et al., 2016)
- Allows for separation of g variance from residual variance for group factors
Questions

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References


