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Confirmatory Factor Analysis of the WJ IV Cognitive: What Does the Standard Battery Measure at School Age?

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Abstract

This study aimed to evaluate the tenability of the proposed scoring/interpretive structure for the Woodcock-Johnson IV Test of Cognitive Abilities (WJ IV COG) Standard Battery configuration of subtests using confirmatory factor analysis (CFA) at school age. Results indicated that a three-factor hierarchical model, consistent with CHC theory (Crystallized Ability, Fluid Reasoning, Short-Term Memory/Working Memory) provided the best fit to the WJ IV COG normative data. Whereas the preferred CHC interpretive structure was largely replicated, indices of interpretive relevance indicated that, among the Stratum II/III attributes that were located, only the omnibus general intelligence dimension should be interpreted with confidence. Nevertheless, several subtests contained adequate specificity to be interpreted in isolation apart from broad abilities. Implications for clinical interpretation are discussed.

Keywords: WJ IV COG, structural validity, evidence-based assessment, CHC

Confirmatory Factor Analysis of the WJ IV Cognitive: What Does the Standard Battery Measure at School Age?

The Woodcock Johnson IV Tests of Cognitive Abilities (WJ IV COG; Schrank et al., 2014b) is one of three distinct (Achievement, Oral Language), co-normed, batteries of the broader Woodcock Johnson IV assessment system (Schrank et al., 2014a). The WJ IV COG features 18 subtests, 10 of which comprise the *Standard Battery*. Remaining subtests can be used in isolation or in various configurations to complement the Standard Battery to form an *Extended* Battery affording users access to all the purported assessment capabilities for the instrument such as selective testing of broad cognitive abilities and the formulation of sundry formative narrow-band aptitude clusters. To wit, it is noted in the Technical Manual (McGrew et al., 2014), “The eight subtests included in the Extended Battery enhance the interpretive information available from the standard battery” (p. 9). A unique feature of the WJ IV COG is that it, like its progenitor, remains the only individually administered measure of cognitive functioning to feature scores associated with all seven consensus broad ability domains from Cattell-Horn-Carroll Theory (CHC; Schneider & McGrew, 2018), the consensus psychometric theory of human cognitive abilities in psychology and education and the CHC taxonomy is frequently characterized by its curators as a veritable periodic table of cognitive elements. Thus, it is not surprising that recent surveys of the assessment practices of school psychologists indicate that the WJ IV is among the most used instruments in clinical training and practice (e.g., Lockwood & Farmer, 2019).

According to the Technical Manual, the WJ IV COG can be administered to examinees ages two to 90 years and beyond. The 10 Standard Battery subtests combine to yield Crystallized Ability (Gc), Fluid Reasoning (Gf), and Short-Term Working Memory (Gsm/wm) cluster scores as well as a full scale General Intellectual Ability (GIA) composite, thought to be a proxy for psychometric *g*. Although cluster scores cannot be derived for the remaining four hypothesized CHC broad abilities in the Standard Battery, each of the remaining dimensions is measured by one of the first seven subtests (Auditory Processing [Ga], Visual Processing [Gv], Long-Term Storage & Retrieval [Glr], and Processing Speed [Gs]).[1] Users are also provided with access to several ancillary composite and clinical clusters depending on the configuration of subtests that are administered (e.g., Brief Intellectual Ability, *Gf-Gc* Composite, Cognitive Efficiency). It should be noted that the Cognitive Efficiency cluster represents a combination of Gsm/wm and Gs tasks and traces its lineage to the origins of the instrument and the since eschewed Cognitive Performance Model method of clinical interpretation as per Woodcock (see Taub & McGrew, 2014).

Unfortunately, no structural validity analyses were conducted on the Cognitive Battery in general nor its Standard Battery in particular. Instead, the internal structure of the WJ IV COG was extrapolated from exploratory (EFA) and confirmatory factor analyses (CFA) of the entire WJ IV battery. This is potentially problematic as it cannot be assumed that a hypothesized sub structure within a proposed measurement model will automatically replicate when the parameters of that model are substantively altered.

Independent Structural Validity Investigations of WJ IV COG Extended

Two recent independent factor analytic investigations (Dombrowski et al., 2017; 2018), examining the structure of the WJ IV COG Extended Battery have raised questions about veracity of the CHC interpretive model posited for the instrument. Dombrowski and colleagues (2017) subjected the 18 subtest Extended Battery to best practice EFA procedures and found that the hypothesized seven-factor CHC solution was poorly aligned and instead an alternative four-

[1] When combined with aligned measures in the Extended Battery, cluster scores are available for all hypothesized CHC broad ability dimensions and additional narrow ability and clinical clusters.

factor model more consistent with Wechsler Theory (Gc, Perceptual Reasoning, Gsm/wm, Gs) provided the best explanation for the normative data at school-age. These results were later replicated in a CFA investigation using the same normative data (Dombrowski et al., 2018). Further, in both studies, resulting indices of interpretive relevance did not support confident interpretation of any of the cluster/composite scores examined beyond the GIA and perhaps Gs.

Purpose of the Current Study

As the results furnished in previous factor analytic investigations illustrate well, the underlying structure of the WJ IV COG-Extended cannot be extrapolated from a broader examination of entire WJ IV battery; similarly, the underlying structure of the more circumspect Standard Battery cannot automatically be inferred from a major extension of that test. Unfortunately, a separate investigation, focusing solely on the Standard Battery has yet to be reported in the literature. Accordingly, the present study used CFA procedures to better clarify the factor structure of the WJ-IV COG to ascertain what the Standard Battery measures at school-age (ages 9-19). Given that administration of that portion of the battery serves as the primary vehicle for users to obtain a comprehensive assessment of intellectual functioning in school and clinical settings, it is believed that the results provided by the present investigation will be instructive for furthering our understanding how the measure should be interpreted.

Method and Analyses

The WJ-IV COG was standardized on a stratified nationally representative sample of 7,416 examines aged 2-90 plus years closely approximating the 2010 United States Census on age, sex, and parent education level. The 9-13 and 14-19 age groups were composed of 1,572 and 1,685 participants, respectively. The WJ IV COG Standard Battery has 10 core subtests (M = 100, SD = 15) that combine to form three cluster scores (M = 100, SD = 15): Gc, Gf, and Gsm/wm as well as an ancillary Cognitive Efficiency score which is billed as a narrow/clinical cluster. The GIA (*M* = 100, *SD* = 15) is a differential weighted composite from the first seven subtests.

The WJ IV COG-Standard subtest correlation matrixes for normative sample participants ages 9-13 and 14-19 were extracted from the Technical Manual and subjected to CFA using EQS, Version 6.2 (West et al., 2012) via maximum likelihood estimation. Five competing models were specified and examined: (a) one-factor; (b) indirect hierarchical models ranging from two- to four-factors featuring the hypothesized CHC dimensions and related narrow band cluster scores; and (c) a bifactor model alternative for the best fitting indirect hierarchical model (see supplemental Figure X.1[2]). In the bifactor model, factors with only two subtest indicators were constrained to be equal to ensure specification. It should be noted that the estimation of conventional correlated (oblique) factors models were not conducted as they required converting individual subtests into artificial latent factors which, though possible in CFA, is not recommend by methodologists as it is not mathematically permissible and can increase the likelihood of encountering local strain (Brown, 2015).

To comport with best practice, multiple indices were examined to evaluate the adequacy of model fit. Specifically, the (a) chi-square (χ^2), (b) comparative fit index (CFI), (c) root mean square error of approximation (RMSEA), (d) standardized root mean square residual (SRMR), and (e) Akaike's information criterion (AIC) and the Bayesian Information Criterion (BIC) were used. Final model retention was based on an evaluation of the degree to which a model provided the best global fit to the data, incremental improvement in fit beyond more parsimonious models, and the absence of local identification issues (Dombrowski et al., 2021). Additionally, indices of

[2] Supplemental tables and figures denoted X.X and are available using the following OSF link (https://osf.io/kehjr/).

interpretive relevance were calculated to produce omega estimates, *H* and PUC consistent with recommended reporting guidelines (e.g., Rodriguez et al., 2016).

Results

Model fit statistics presented in Table 1 illustrate increasingly better fit from one- to three-factors across school-age consistent with CHC theory. Fit statistics indicate that a hierarchical three-factor model (Model 3 [Gc, Gf, Gsm/wm]) provided the best fit to the WJ IV COG normative data among the competing indirect hierarchical models that were examined at both ages 7-13 and 14-19. Global fit statistics for that model were univocally good and revealed adequate incremental improvement in fit from the previous two factor model. Attempts to specify the hypothesized Cognitive Efficiency dimension as an equivalent broad ability dimension at Stratum II or as a superordinate factor as per Taub and McGrew (2014) did not result in model convergence indicating that dimension is likely not viable for the instrument. Given the fact that each of the group-specific CHC factors are just determined in Model 3, the corresponding bifactor expression of that model yielded equivalent fit statistics. As a result, Model 3 was retained as the best explanation for the data as that model yielded lower AIC and BIC values compared to the bifactor model and it better coheres with publisher theory (see Figures 1 and X.2).

Various metrics of scale interpretability (e.g., omega-hierarchical, omega-hierarchical subscale, *H*, ECV) are furnished for both the 9-13 and 14-19 aged models. Indices were calculated using the approximation for the Schmid-Leiman residualization procedure for CFA outlined by Keith & Reynolds (2018). Supplemental tables X.1 and X.2 illustrate well that users of the instrument can interpret the general ability dimension (i.e., GIA) with confidence but that there is less reliable unit-weighted variance for any of the posited CHC group-specific factors permitting similar interpretive guidance. These results are consistent with previous factor analytic studies with respect to the Extended Battery subscores (e.g., Dombroski et al., 2017, 2018). Interestingly, variance apportionment at the subtest-level (see Figures X.3 and X.4) revealed that, many of the subtests contain adequate specificity to potentially be interpreted in isolation given conventional rules of thumb (i.e., Kaufman, 1994), a finding at odds with the bulk of contemporary interpretive guidance in many clinical manuals and guidebooks (Farmer et al., 2021).

Discussion

As noted by Popper (1963), replication is the coin of the realm in scientific psychology. That is, every scoring/interpretive structure posited for a measurement instrument represents a hypothesis that can be independently tested and subjected to falsification. The results of the present investigation illustrate well that establishing construct validity for an instrument as complex as the WJ IV COG is not an *all or nothing* proposition as each of its intended uses is deserving of its own unique evaluation (Cronbach & Meehl, 1955). In contrast to previous factor analytic results evaluating the structure of the Extended Battery, the present results largely support the more parsimonious CHC-derived scoring/interpretive structure for the Standard Battery with the exception of the posited narrow Cognitive Efficiency cluster. It is unclear why that dimension failed to clearly emerge in the data. It is important to highlight that the *clinical/narrow* clusters on the WJ IV COG are largely reconfigurations of previously apportioned subtests and thus represent what can be regarded as pseudo-composites given their lack of representation within the structural validity studies reported in the Technical Manual.

Nevertheless, variance apportionment and the resulting indices of interpretive relevance indicate that the Standard Battery affords users with a relatively robust indicator of general ability and, though located, the CHC group-specific factors account for relatively paltry portions of unique variance apart from *g*. Specificity estimates indicate that many of the WJ IV COG subtests may be deserving of interpretation in isolation (e.g., General Information, Concept Formation, Letter-Pattern Matching, Story Recall, Visualization), which would seemingly buttress the use of the scholastic-aptitude clusters outlined in the Technical Manual for better linking hypothesized cognitive-achievement relationships at the individual-level. Nevertheless, these results must be interpreted in consideration of the limitation that the more parsimonious Standard Battery interpretive structure, necessarily precludes the estimation of several possible CHC broad abilities, which several subtests are thought to map onto. Thus, these may very well represent upper-bound specificity estimates for those metrics.

As with any study, this investigation is not without limitations. Most notably, Standard Battery configuration of subtests poses limitations on model complexity in CFA. For example, it was necessary to model several subtests as loading directly on *g* even though they do not contribute to the measurement of the GIA. Whereas this may inflate the variance attributable to *g*, this accommodation was necessary in order to permit the hierarchical models that were examined as CFA does not permit the specification of orphan indicators. Additionally, whereas the Gf dimension was located across the school-age range, its second-order loading on *g* approached unity (.96-.99) in both final models that were retained. Such isomorphism is not unique to the WJ IV COG although adjudication of this issue is beyond the scope of the present manuscript, previous research suggests that Gf is a psychological construct apart from *g* (see Golay et al., 2013). Further, given these analyses were limited to ages 9-19, it remains unclear the degree to which they may or may not replicate at other age ranges for the instrument. It is also instructive to note that previous validation work on the Kaufman Assessment Battery for Children-Second Edition (KABC-II; Kaufman & Kaufman, 2004) failed to locate a posited Gf dimension prior to age 7.

In closing, the WJ IV COG-Standard appears to measure intended CHC constructs as designed and likely affords users a valid assessment of broad cognitive functioning that may be used as a base to supplement more focal selective testing of other CHC dimensions available to users in the Extended Battery or through cross-battery assessment utilizing additional measures (e.g., Flanagan et al., 2013). However, the failure to locate the hypothesized Cognitive Efficiency dimension suggests caution in moving beyond the primary CHC interpretive model to the panoply of narrow/clinical scores until additional information emerges to support that there is adequate discriminant validity at that level of the instrument (Gonzalez et al., 2021).

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Table 1

Confirmatory Factor Analysis Fit Statistics for WJ IV COG 10 Subtest Standard Battery Configuration for Normative Sample Participants Ages 9-19

Model	χ^2	*df*	p^a	CFI	SRMR	RMSEA	90% RMSEA	BIC	AIC
Ages 9-13 (*n* = 1,572)									
1. One factor (*g*)	876.69	35	.00	.828	.060	.124	[.117, .131]	125773	125666
2. Two factors (Gc, Gf)	367.52*	33	.00	.932	.042	.080	[.073, .088]	125279	125161
3. Three factors (Gc, Gf, Gsm)	347.02**	32	.00	.936	.041	.079	[.072, .087]	125266	125142
4. Four factors (Gc, Gf, Gsm, CE)		**Model specification error, model fit statistics not reported**							
5. Bifactor[b] model 3	347.020	32	.00	.936	.041	.079	[.072, .087]	125288	125148
Ages 14-19 (*n* = 1,685)									
1. One factor (*g*)	1036.72	35	.00	.847	.059	.130	[.124, .137]	133593	133484
2. Two factors (Gc, Gf)	525.28*	33	.00	.925	.045	.094	[.087, .101]	133096	132977
3. Three factors (Gc, Gf, Gsm)	481.06**	32	.00	.932	.043	.091	[.084, .099]	133059	132934
4. Four factors (Gc, Gf, Gsm, CE)		**Model specification error, model fit statistics not reported**							
5. Bifactor[b] model 3	481.06	32	.00	.932	.043	.091	[.084, .099]	133082	132940

Note. WJ IV COG = Woodcock-Johnson IV Tests of Cognitive Abilities. CFI = comparative fit index; SRMR = standardized root mean square residual; RMSEA = root mean square error of approximation; BIC = Bayesian information criterion; AIC = Akaike information criterion. *g* = general intelligence, Gc = Comprehension-Knowledge, Gf = Fluid Reasoning, Gsm = Short-Term Working Memory, NR = Numbers reversed, CE = Cognitive Efficiency.

[a] *p*-values rounded to nearest hundredth thus they are not exact estimates.

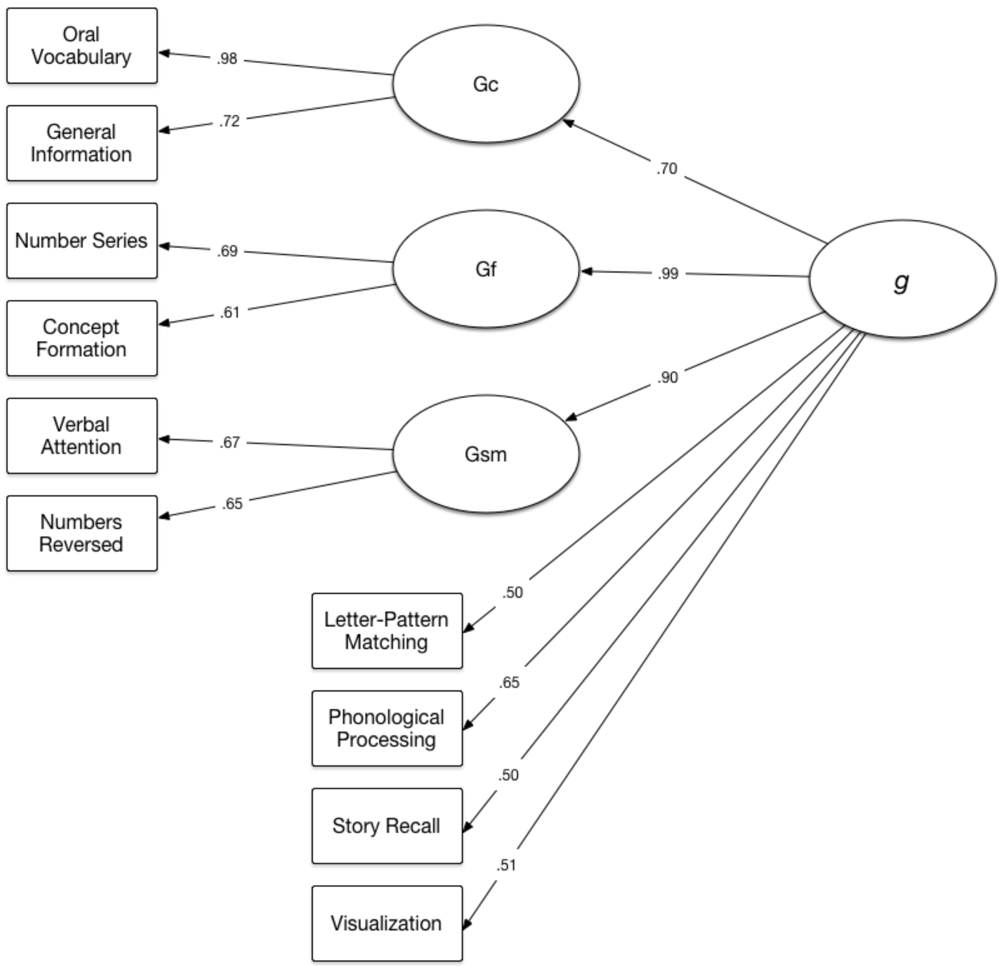
[b] Group-specific factors with less than three indicators were constrained in order to ensure identification.

[*] Statistically different ($p < .05$) from model one.

[**] Statistically different ($p < .05$) from model two.

Figure 1

CHC-Based Higher-order measurement model, with standardized coefficients for WJ-IV COG normative sample ages 9-13 (n = 1,572) 10 Standard Battery Subtest Configuration.



Note. *g* = general intelligence, Gc = Crystallized Ability, Gf = Fluid Reasoning, Gsm = Short-Term Memory. For clarity of presentation, residual and disturbance terms are omitted. All coefficients were statistically significant ($p < .05$).

Table X.1
Sources of Variance in the WJ IV COG for the 10 Subtest Standard Battery Ages 9-13 (n = 1,572) According to a hierarchical model with three first-order factors

	General		F1: Gc		F2: Gf		F3: Gsm			
Subtest	*b*	S^2	*b*	S^2	*b*	S^2	*b*	S^2	h^2	u^2
Oral Vocabulary	.686	.471	**.491**	**.241**					.712	.288
General Information	.506	.256	**.269**	**.072**					.328	.672
Number Series	.688	.473			**.007**	**.000**			.473	.527
Concept Formation	.601	.361			**.006**	**.000**			.361	.639
Verbal Attention	.597	.356					**.089**	**.008**	.364	.636
Numbers Reversed	.577	.333					**.084**	**.007**	.340	.660
Letter-Pattern Matching	.495	.245							.245	.755
Phonological Processing	.653	.426							.426	.574
Story Recall	.499	.249							.249	.751
Visualization	.511	.261							.261	.739
Total Variance		.343		.031		.000		.001	.376	.624
ECV		.913		.083		.000		.004		
ωh/ωhs		.832		.195		.000		.011		
H		.846		.283		.000		.015		

Note. *b* = residualized standardized loading of subtest on factor using the Schmid and Leiman (1957) orthogonalization procedure as per Keith and Reynolds (2018), S^2 = variance, h^2 = communality, u^2 = uniqueness, ECV = explained common variance, ωh = omega-hierarchical (general factor), ωhs = omega-hierarchical subscale (group factors), H = construct replicability index.

Table X.2
Sources of Variance in the WJ IV COG for the 10 Subtest Standard Battery Ages 14-19 (n = 1,685) According to a hierarchical model with three first-order factors

	General		F1: Gc		F2: Gf		F3: Gsm			
Subtest	*b*	*S*²	*b*	*S*²	*b*	*S*²	*b*	*S*²	*h*²	*u*²
Oral Vocabulary	.740	.548	**.385**	**.148**					.696	.304
General Information	.587	.345	**.242**	**.059**					.403	.597
Number Series	.708	.501			**.044**	**.002**			.503	.497
Concept Formation	.649	.421			**.038**	**.001**			.423	.577
Verbal Attention	.590	.348					**.104**	**.011**	.359	.641
Numbers Reversed	.640	.410					**.121**	**.015**	.424	.576
Letter-Pattern Matching	.541	.293							.293	.707
Phonological Processing	.703	.494							.494	.506
Story Recall	.540	.292							.292	.708
Visualization	.573	.328							.328	.672
Total Variance		.398		.021		.000		.003	.421	.579
ECV		.944		.049		.001		.006		
ωh/ωhs		.863		.129		.002		.018		
H		.875		.191		.003		.025		

Note. *b* = residualized standardized loading of subtest on factor using the Schmid and Leiman (1957) orthogonalization procedure as per Keith and Reynolds (2018), *S*² = variance, *h*² = communality, *u*² = uniqueness, ECV = explained common variance, ωh = omega-hierarchical (general factor), ωhs = omega-hierarchical subscale (group factors), H = construct replicability index.

Figure X.1

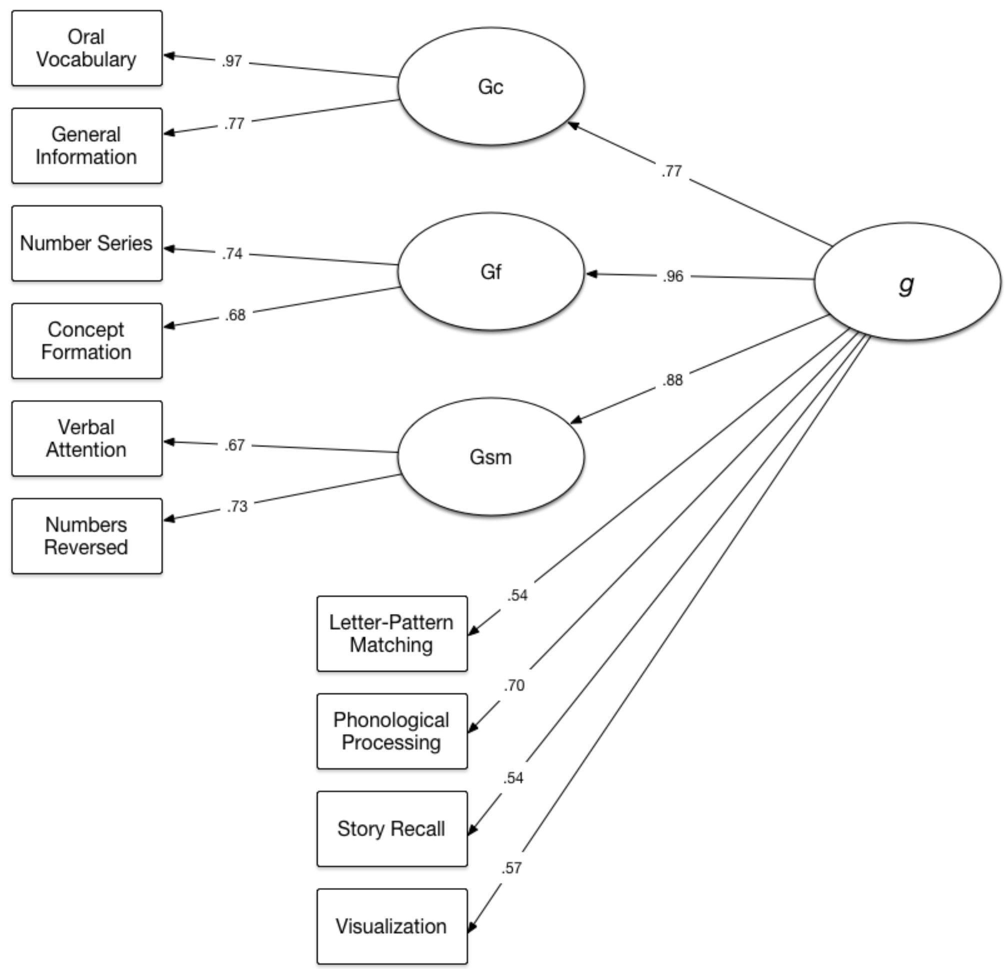
WJ-IV COG Standard Battery Subtest configuration for CFA modes with 1-4 factors.

	Model 1	**Model 2**			**Model 3**				**Model 4**					**Model 5 Bifactor**			
Subtest	*g*	*g*	F1	F2	*g*	F1	F2	F3	*g*	F1	F2	F3	F4	*g*	F1	F2	F3
OV	*		*			*				*				*	*		
GI	*		*			*				*				*	*		
NS	*			*			*				*			*		*	
CF	*			*			*				*			*		*	
VA	*	*						*				*		*			*
NR	*	*						*				*	*	*			*
LPM	*	*			*								*	*			
PP	*	*			*				*					*			
SR	*	*			*				*					*			
VZ	*	*			*				*					*			

Note. OV = Oral Vocabulary, GI = General Information, NS = Number Series, CF = Concept Formation, VA = Verbal Attention, NR = Numbers Reversed, LPM = Letter-Pattern Matching, PP = Phonological Processing, SR = Story Recall, VZ = Visualization. All models include a higher-order general factor except for the bifactor model. Due to under identification, oblique factors models could not be estimated.

Figure X.2

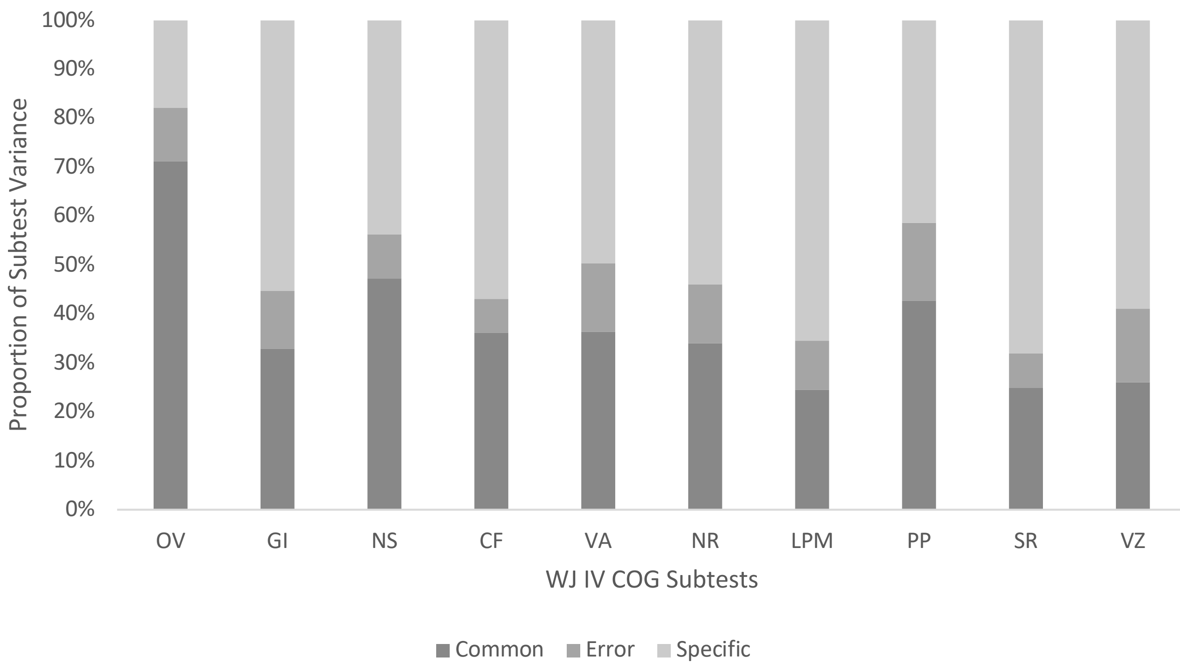
CHC-Based Higher-order measurement model (3), with standardized coefficients for WJ-IV COG normative sample ages 14-19 (n = 1,685) 10 Standard Battery Subtest Configuration.



Note. *g* = general intelligence, Gc = Crystallized Ability, Gf = Fluid Reasoning, Gsm = Short-Term Memory. For clarity of presentation, residual and disturbance terms are omitted. All coefficients were statistically significant ($p < .05$).

Figure X.3

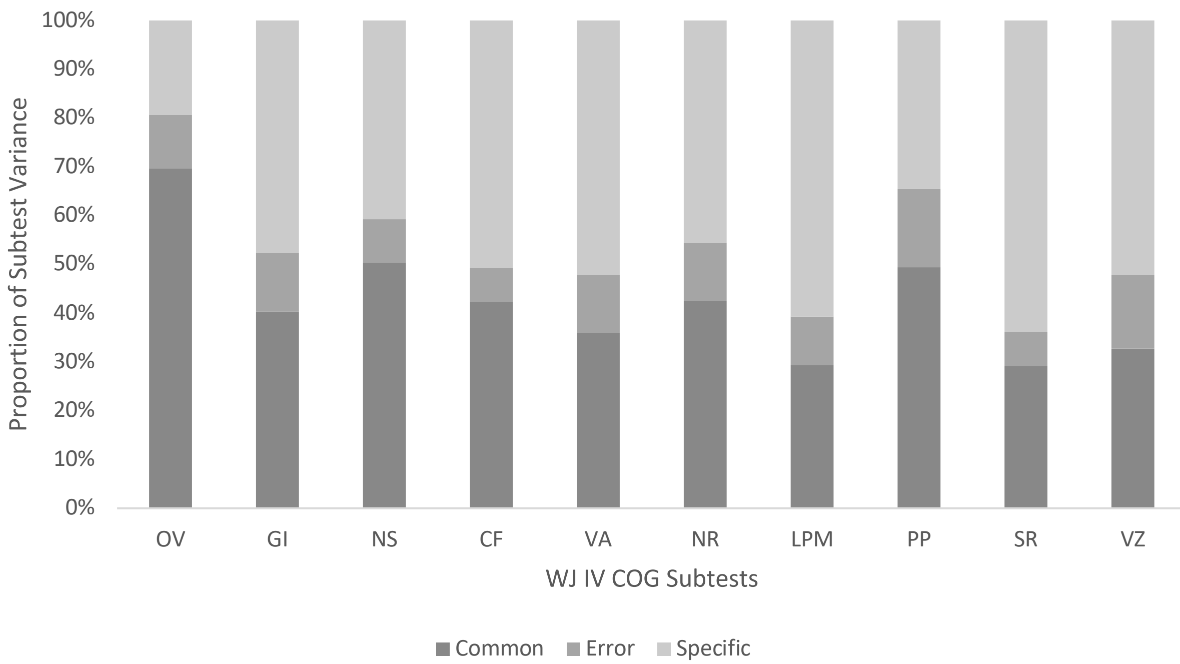
Proportion of common, specific, and error variance in the WJ IV COG Standard Battery Subtests for normative participants ages 9-13.



Note. OV = Oral Vocabulary, GI = General Information, NS = Number Series, CF = Concept Formation, VA = Verbal Attention, NR = Numbers Reversed, LPM = Letter-Pattern Matching, PP = Phonological Processing, SR = Story Recall, VZ = Visualization.

Figure X.4

Proportion of common, specific, and error variance in the WJ IV COG Standard Battery Subtests for normative participants ages 14-19.



Note. OV = Oral Vocabulary, GI = General Information, NS = Number Series, CF = Concept Formation, VA = Verbal Attention, NR = Numbers Reversed, LPM = Letter-Pattern Matching, PP = Phonological Processing, SR = Story Recall, VZ = Visualization.