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# Confirmatory Factor Analysis of the WAIS-IV/WMS-IV

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## Abstract

The Wechsler Adult Intelligence Scale–fourth edition (WAIS-IV) and the Wechsler Memory Scale–fourth edition (WMS-IV) were co-developed to be used individually or as a combined battery of tests. The independent factor structure of each of the tests has been identified; however, the combined factor structure has yet to be determined. Confirmatory factor analysis was applied to the WAIS-IV/WMS-IV Adult battery (i.e., age 16-69 years) co-norming sample ($n$ = 900) to test 13 measurement models. The results indicated that two models fit the data equally well. One model is a seven-factor solution without a hierarchical general ability factor: Verbal Comprehension, Perceptual Reasoning, Processing Speed, Auditory Working Memory, Visual Working Memory, Auditory Memory, and Visual Memory. The second model is a five-factor model composed of Verbal Comprehension, Perceptual Reasoning, Processing Speed, Working Memory, and Memory with a hierarchical general ability factor. Interpretative implications for each model are discussed.

## Keywords

WAIS-IV, WMS-IV, joint factor analysis, confirmatory factor analysis, memory, working memory, intelligence

The factor structure of the Wechsler intelligence scales, adult, child, and international versions, has been the subject of numerous research studies. For the editions of these tests published in the past two decades, there is strong evidence that a four-factor model—Verbal Comprehension, Perceptual Reasoning, Working Memory, and Processing Speed—best describes the latent structure of the intelligence scales (Bowden, Lissner, McCarthy, Weiss, & Holdnack, 2007; Bowden, Weiss, Holdnack, Bardenhagen, & Cook, 2008; Dickinson, Iannone, & Gold, 2002; Donders, & Warschausky, 1996; Taub, McGrew, & Witta, 2004; Wechsler, 2003, 2008); although some studies disagree with such conclusion (Kaufmann, Lichtenberger, & McLean, 2001; Keith, Fine, Taub, Reynolds, & Kranzler, 2006). Although there is a substantial body of research evaluating the factor structure of the Wechsler intelligence scales, the study on the Wechsler memory scales has not been as extensive, and obtaining consistent factor structure across studies and test editions has been elusive (Wechsler, 2009).

Factor analytic studies of previous versions of the Wechsler memory scale have yielded inconsistent results. Initial factor analytic results published for the Wechsler Memory Scale–third edition (WMS-III) indicated that a five-factor model (i.e., Auditory Immediate, Auditory Delayed, Visual Immediate, Visual Delayed, and Working Memory) best fit the data from the normative sample (Wechsler, 1997). Subsequent reanalysis of the factor structure of WMS-III found that a five-factor model yielded inadmissible parameter estimates (i.e., correlations >1.0) because of the high correlation between immediate and delayed memory measures (Millis, Malina, Bowers, & Ricker, 1999). Additionally, low communality estimates for Faces contributed to model specification errors for the visual memory factor (Millis et al., 1999). This finding was confirmed by Price, Tulsky, Millis, & Weiss (2002). For special groups, a two-factor model consisting of working memory and general memory was found in a large left and right temporal lobe epilepsy sample (Wilde et al., 2003); whereas four factors—Auditory, Visual, Working Memory, and Learning—were reported for a mixed clinical and control sample (Burton, Ryan, Axelrod, Schellenberger, & Richards, 2003). Inconsistent findings suggest that the relationship among memory scales may be moderated by methodological and cognitive factors beyond memory itself.

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Memory functioning cannot be directly assessed; rather, memory is measured in the context of other cognitive skills such as visual spatial or verbal abilities (e.g., story recall requires intact language functioning). Heilbronner (1992) details the nature of additional cognitive functions that affect performance on visual memory tests and concludes that the concept of pure visual memory measures is untenable. The methodology used to assess memory (e.g., free recall, learning, and recognition) could also affect the psychometric properties of the test and its relationship to other memory measures (Compton, Sherer, & Adams, 1992). Therefore, performance on the memory tests could vary by the nature of additional cognitive skills measured and the methodology employed, which may facilitate or inhibit efficient memory storage and retrieval and, in turn, attenuate or facilitate the correlation between two memory measures. These variations among memory measures result in memory tests being only moderately correlated with each other (Compton et al., 1992; Golden, White, Combs, Morgan, & McLane, 1999).

The first combined factor analysis of the Wechsler Adult Intelligence Scale (WAIS) and the original WMS clarified the construct validity of the tests comprising the WMS by analyzing the factor structure in the context of other measures of verbal and visuospatial skills, attention, and processing speed (Larrabee, Kane, & Schuck, 1983). This exploratory factor analysis yielded a memory factor defined by Logical Memory and Paired Associate Learning, an information/orientation factor, and an attention/concentration factor defined by Digit Span, Arithmetic, and Mental Control. Of particular interest, WMS Visual Reproduction loaded more strongly with a WAIS visuospatial ability factor (.70) than with the memory factor (.09). Subsequently, Larrabee, Kane, Schuck, and Francis (1985) factored immediate recall and delayed recall Logical Memory and Visual Reproduction subtests in separate factor analyses, thereby controlling for method variance (Larrabee, 2003), and found that Immediate Visual Reproduction loaded more strongly with a visuospatial ability factor defined by Block Design and Object Assembly than with a memory factor defined by Logical Memory and Paired Associate Learning. When delayed recall scores (e.g., Delayed Logical Memory and Visual Reproduction) were factored, the loading pattern of Delayed Visual Reproduction shifted so that the primary loading was with the memory factor, with a secondary loading on the visuospatial ability factor. This basic finding (stronger association with visuospatial ability for Immediate Visual Reproduction, with stronger association with memory for Delayed Visual Reproduction) was replicated by Leonberger, Nicks, Larrabee, and Goldfader (1992) in a factor analysis of Wechsler Adult Intelligence Scale–Revised (WAIS-R), Wechsler Memory Scale–Revised (WMS-R), and Halstead–Reitan Neuropsychological Battery subtests.

In a series of articles employing confirmatory factor analysis, Bowden and colleagues initially found that a five-factor model: Verbal Comprehension, Perceptual Organization, Attention–Concentration/Working Memory, Verbal Memory, and Visual Memory, best accounted for the joint factor structure of the WAIS-R and WMS-R in a nonclinical sample (Bowden, Carstairs, & Shores, 1999) and a substance abuse sample (Bowden et al., 2001). In a later study, however, a six-factor model that also included Processing Speed was supported in clinical and community samples (Bowden, Cook, Bardenhagen, Shores, & Carstairs, 2004). The WAIS-R and WMS-R studies indicate that five or six factors are supported with auditory and visual memory factors identified from the memory scale.

The Wechsler intelligence and memory scales were co-normed for the first time for the third edition of the tests (Tulsky & Ledbetter, 2000). Tulsky and Price (2003) completed an extensive evaluation of the joint factor structure of the WAIS-III and WMS-III. They reported that a six-factor model, Verbal Comprehension, Perceptual Organization, Working Memory, Processing Speed, Visual Memory, and Auditory Memory, was best supported by the data. Model specification errors were observed when immediate and delayed memory factors were evaluated in the same factor analysis; additionally, Faces was observed to have poor fit on any factor. The model fit was best when subtests were allowed to load on multiple factors specifically for Arithmetic, Spatial Span, Picture Arrangement, and Visual Reproduction (Tulsky, Ivnik, Price, & Wilkins, 2003).

The WAIS-IV has a very similar subtest and index structure as its predecessor, the WAIS-III (Wechsler, 2008). The primary differences are the inclusion of a new subtest, Visual Puzzles, on the Perceptual Reasoning index and the addition of a sequencing procedure to the Digit Span subtest. The four-factor model of Verbal Comprehension, Perceptual Reasoning, Working Memory, and Processing speed was confirmed by factor analysis (Wechsler, 2008). The WMS-IV, however, was substantially revised from the previous edition (Wechsler, 2009). At the subtest level, there is a new visual memory subtest, Designs, and two new visual working memory subtests: Spatial Addition and Symbol Span. The index structure includes Verbal Memory, Visual Memory, Visual Working Memory, Immediate Memory, and Delayed Memory. The Visual Memory, Auditory Memory, and Visual Working Memory indexes were confirmed by factor analysis (Wechsler, 2009).

The purpose of the current study is to evaluate the joint factor structure of the most recent editions of the Wechsler intelligence and memory scales. Although the six-factor model has received support in previous editions, the addition of new visual working memory subtests may result in a split of the working memory factor into two components: auditory and visual. Therefore, the current analysis will evaluate multiple models that include up to seven factors. It is also anticipated that allowing subtests to load on multiple factors will improve model fit. It is not expected that confirmatory factor analysis can differentiate immediate from delayed memory functioning as this often leads to model specification errors consequent to method variance. Therefore, only the delayed memory scores are used in this analysis, which should provide better evaluation of the construct validity of WMS-IV visual memory tasks in particular (Larrabee et al., 1985).

## Method

### *Participants*

Participants for this study included 900 healthy people, between 16 and 69 years of age, from the WAIS-IV/WMS-IV standardization sample. All participants were administered both the WAIS-IV and the WMS-IV adult battery. Older adults who were administered the WMS-IV (i.e., age 65-90 years) were not included in these analyses, since not all subtests were administered to this group. The sample demographics were based on and are consistent with the 2005 U.S. Census results. For a complete list of exclusion criteria for the standardization sample, the reader is referred to the *WMS-IV Technical and Interpretive Manual* (Wechsler, 2009).

### *Measures*

The WAIS-IV (Wechsler, 2008) is a battery of tests designed to evaluate intellectual abilities. The WAIS-IV consists of 10 primary subtests (Vocabulary, Information, Similarities, Digit Span, Arithmetic, Block Design, Matrix Reasoning, Visual Puzzles, Coding, and Symbol Search). The primary subtests yield four Index scores (Verbal Comprehension, Perceptual Reasoning, Working Memory, and Processing Speed) and an overall Full-Scale IQ.

The WMS-IV (Wechsler, 2009) is a battery of tests designed to evaluate working memory, learning, immediate and delayed recall, and recognition of information presented in verbal and visual modalities. The WMS-IV is divided into an adult battery (16-69 years) and an older adult battery (65-90 years). The current study uses the two working memory subtests and the four delayed free recall conditions from the adult battery. The subtests include Logical Memory (recall for a short story); Verbal Paired Associates (recall for related and unrelated word pairs); Designs (recall of spatial locations and visual details); Visual Reproduction (recall of geometric designs); Spatial Addition (ability to manipulate visual-spatial information in working memory); and Symbol Span (ability to manipulate designs in working memory). These subtests contribute to four WMS-IV Index scores: Visual Working Memory, Auditory Memory, Visual Memory, and Delayed Memory. The age-adjusted scaled scores of the primary subtests in the WAIS-IV and WMS-IV were used in analysis.

### *Models*

Since previous factor analytic research on the WAIS-IV, the WMS-IV, and the combined earlier versions of the WAIS and WMS is available, it was possible to delineate cognitive models that could be evaluated for their fit the data. Thus, the models of cognitive functioning proposed for evaluation are based on previous research, the theoretical rationale for the tests, as well as findings from exploratory factor analysis. The models of primary interest are composed of five, six, and seven factors with five core abilities related to Verbal Comprehension, Perceptual Reasoning, Working Memory, Processing Speed, and General Memory. Additional factors are derived from separating modality (e.g., auditory vs. visual) for Working Memory and General Memory.

To determine the best measurement model, multiple models were tested and model fit statistics compared. Each model was compared with a two-factor model defined as Verbal Comprehension and Perceptual Reasoning. The models evaluated initially are hierarchical with a first-order g-factor and second-order (Models 2Ha-7Ha), and third-order (Models 5Hb-7Hb) factors. These models are specified in Table 1.

Confirmatory factor analysis (CFA) is designed to evaluate the factor structure specified by researchers a priori. The specific relations between observed variables (e.g., subtests) and a latent variable (e.g., Auditory Memory) and among latent variables are specified in advance. The model is tested to determine if it does a good job of explaining the correlations among the observed variables. If it does, this is supporting evidence for the validity of the model. CFA is preferred to exploratory factor analysis when an explicit theory of the factor structure is present or there are competing models in the research literature (Stevens, 1996).

Goodness-of-fit measures based on the chi-square statistic (i.e., likelihood ratio chi-square statistic) are used to evaluate model fit. The chi-square statistic is sensitive to large sample sizes; therefore, additional fit measures are used to evaluate the models (Byrne, 2001; Schumacker & Lomax, 2004; Thompson, 2000). Five additional model-fit statistics were used: adjusted goodness-of-fit index (AGFI; Jöreskog & Sörbom, 1993), root mean squared error of approximation (RMSEA; Steiger, 1990), root mean square residual (RMSR), Tucker–Lewis nonnormed fit index (TLI; Tucker & Lewis, 1973), comparative fit index (CFI), and Schwarz's Bayesian information criterion (BIC; Schwartz, 1978). Good model fit is observed if AGFI values exceed

**Table 1.** Model Specifications for Initial Confirmatory Analysis

| Model | Hierarchical Level | Factors | Variables |
|---|---|---|---|
| 2Ha (three-factor) | 1 | g-Factor | All WAIS-IV/WMS-IV subtests |
| | 2 | Verbal | Vocabulary, Similarities, Information, Arithmetic, Digit Span, Logical Memory Delayed, Verbal Paired Associates Delayed |
| | 2 | Perceptual | Block Design, Visual Puzzles, Matrix Reasoning, Coding, Symbol Search, Symbol Span, Spatial Addition, Designs Delayed, Visual Reproduction Delayed |
| 3Ha (four-factor) | 1 | g-Factor | All WAIS-IV/WMS-IV subtests |
| | 2 | Verbal | Vocabulary, Similarities, Information |
| | 2 | Perceptual | Block Design, Visual Puzzles, Matrix Reasoning, Coding, Symbol Search |
| | 2 | Memory | Arithmetic,[a] Digit Span, Logical Memory Delayed, Verbal Paired Associates Delayed, Symbol Span, Spatial Addition,[b] Designs Delayed, Visual Reproduction Delayed[c] |
| 3Hb (four-factor) | 1 | g-Factor | All WAIS-IV/WMS-IV subtests |
| | 2 | Verbal | Vocabulary, Similarities, Information, Logical Memory Delayed, Verbal Paired Associates Delayed |
| | 2 | Perceptual | Block Design, Visual Puzzles, Matrix Reasoning, Coding, Symbol Search, Designs Delayed, Visual Reproduction Delayed |
| | 2 | Working Memory | Arithmetic,[a] Digit Span, Symbol Span, Spatial Addition[b] |
| 3Hc (four-factor) | 1 | g-Factor | All WAIS-IV/WMS-IV subtests |
| | 2 | Verbal | Vocabulary, Similarities, Information, Arithmetic, Digit Span, Logical Memory Delayed, Verbal Paired Associates Delayed |
| | 2 | Perceptual | Block Design, Visual Puzzles, Matrix Reasoning, Symbol Span, Spatial Addition, Designs Delayed, Visual Reproduction Delayed |
| | 2 | Processing Speed | Coding, Symbol Search |
| 3Hd (four-factor) | 1 | g-Factor | All WAIS-IV/WMS-IV subtests |
| | 2 | Verbal | Vocabulary, Similarities, Information |
| | 2 | Perceptual | Block Design, Visual Puzzles, Matrix Reasoning |
| | 2 | Cognitive Proficiency | Arithmetic,[a] Digit Span, Logical Memory Delayed, Verbal Paired Associates Delayed, Symbol Span, Spatial Addition,[b] Designs Delayed, Visual Reproduction Delayed, Coding, Symbol Search |
| 4Ha (five-factor) | 1 | g-Factor | All WAIS-IV/WMS-IV subtests |
| | 2 | Verbal | Vocabulary, Similarities, Information, Logical Memory Delayed, Verbal Paired Associates Delayed |
| | 2 | Perceptual | Block Design, Visual Puzzles, Matrix Reasoning, Designs Delayed, Visual Reproduction Delayed |
| | 2 | Processing Speed | Coding, Symbol Search |
| | 2 | Working Memory | Arithmetic,[a] Digit Span, Symbol Span, Spatial Addition |
| 4Hb (five-factor) | 1 | g-Factor | All WAIS-IV/WMS-IV subtests |
| | 2 | Verbal | Vocabulary, Similarities, Information |
| | 2 | Perceptual | Block Design, Visual Puzzles, Matrix Reasoning |
| | 2 | Processing Speed | Coding, Symbol Search |
| | 2 | Memory | Arithmetic,[a] Digit Span, Symbol Span, Spatial Addition,[b] Logical Memory Delayed, Verbal Paired Associates Delayed, Designs Delayed, Visual Reproduction Delayed[3] |
| 5Ha (six-factor) | 1 | g-Factor | All WAIS-IV/WMS-IV subtests |
| | 2 | Verbal | Vocabulary, Similarities, Information |
| | 2 | Perceptual | Block Design, Visual Puzzles, Matrix Reasoning |
| | 2 | Processing Speed | Coding, Symbol Search |

*(continued)*

**Table 1. (continued)**

| Model | Hierarchical Level | Factors | Variables |
|---|---|---|---|
| | 2 | Working Memory | Arithmetic,[a] Digit Span, Symbol Span, Spatial Addition[b] |
| | 2 | Memory | Logical Memory Delayed, Verbal Paired Associates Delayed, Designs Delayed, Visual Reproduction Delayed[c] |
| 6Ha (seven-factor) | 1 | g-Factor | All WAIS-IV/WMS-IV subtests |
| | 2 | Verbal | Vocabulary, Similarities, Information |
| | 2 | Perceptual | Block Design, Visual Puzzles, Matrix Reasoning |
| | 2 | Processing Speed | Coding, Symbol Search |
| | 2 | Working Memory | Arithmetic,[a] Digit Span, Symbol Span, Spatial Addition[b] |
| | 2 | Auditory Memory | Logical Memory Delayed, Verbal Paired Associates Delayed |
| | 2 | Visual Memory | Designs Delayed, Visual Reproduction Delayed[c] |
| 7Ha (eight-factor) | 1 | g-Factor | All WAIS-IV/WMS-IV subtests |
| | 2 | Verbal | Vocabulary, Similarities, Information |
| | 2 | Perceptual | Block Design, Visual Puzzles, Matrix Reasoning |
| | 2 | Processing Speed | Coding, Symbol Search |
| | 2 | Auditory Working Memory | Arithmetic,[a] Digit Span |
| | 2 | Visual Working Memory | Symbol Span, Spatial Addition[b] |
| | 2 | Auditory Memory | Logical Memory Delayed, Verbal Paired Associates Delayed |
| | 2 | Visual Memory | Designs Delayed, Visual Reproduction Delayed[c] |
| 5Hb (six-factor) | 1 | g-Factor | All WAIS-IV/WMS-IV subtests |
| | 2 | Verbal | Vocabulary, Similarities, Information |
| | 2 | Perceptual | Block Design, Visual Puzzles, Matrix Reasoning |
| | 3 | Processing Speed | Coding, Symbol Search |
| | 3 | Working Memory | Arithmetic,[a] Digit Span, Symbol Span, Spatial Addition[b] |
| | 3 | Memory | Logical Memory Delayed, Verbal Paired Associates Delayed, Designs Delayed, Visual Reproduction Delayed[c] |
| 6Hb (seven-factor) | 1 | g-Factor | All WAIS-IV/WMS-IV subtests |
| | 2 | Verbal | Vocabulary, Similarities, Information |
| | 2 | Perceptual | Block Design, Visual Puzzles, Matrix Reasoning |
| | 3 | Processing Speed | Coding, Symbol Search |
| | 3 | Working Memory | Arithmetic,[a] Digit Span, Symbol Span, Spatial Addition[b] |
| | 3 | Auditory Memory | Logical Memory Delayed, Verbal Paired Associates Delayed |
| | 3 | Visual Memory | Designs Delayed, Visual Reproduction Delayed[c] |
| 7Hb (eight-factor) | 1 | g-Factor | All WAIS-IV/WMS-IV subtests |
| | 2 | Verbal | Vocabulary, Similarities, Information |
| | 2 | Perceptual | Block Design, Visual Puzzles, Matrix Reasoning |

*(continued)*

**Table 1. (continued)**

| Model | Hierarchical Level | Factors | Variables |
|---|---|---|---|
| | 2 | Processing Speed | Coding, Symbol Search |
| | 3 | Auditory Working Memory | Arithmetic,[a] Digit Span |
| | 3 | Visual Working Memory | Symbol Span, Spatial Addition[b] |
| | 3 | Auditory Memory | Logical Memory Delayed, Verbal Paired Associates Delayed |
| | 3 | Visual Memory | Designs Delayed, Visual Reproduction Delayed[c] |

*Note.* WAIS-IV = Wechsler Adult Intelligence Scale–fourth edition; WMS-IV = Wechsler Memory Scale–fourth edition. Models 5Hb, 6Hb, and 7Hb represent three-level hierarchy with working memory and memory nested within verbal and perceptual factors, which are nested within a general ability factor.

a. Arithmetic cross-loads on Verbal.

b. Spatial Addition cross-loads on Perceptual.

c. Visual Reproduction Delayed cross-loads on Perceptual.

.90 or .95 (Thompson, 2000), CFI equals .95 or higher (Hu & Bentler, 1999), and when RMSEA values are .05 or less with adequate fit associated with RMSEA values up to .08 (Browne & Cudeck, 1993). Larger values indicate better fit for the TLI and smaller values for RMSR and BIC. The comparisons of the Bayesian criteria do not require models to be nested. As Raftery (1993) suggested, a difference of more than 10 points in BICs indicates strong evidence for model preference.

## Results

The SAS® program was used to conduct the CFA of WAIS-IV/WMS-IV. The results of the goodness-of-fit model analysis are presented in Table 2. Of the 13 models tested, the best fit statistics are observed for Model 7Ha. This model specifies a general ability factor at the top of the hierarchy and seven second-order factors (i.e., Verbal Comprehension, Perceptual Reasoning, Processing Speed, Auditory Working Memory, Visual Working Memory, Auditory Memory, and Visual Memory). The AGFI of .93 and RMSEA of .058 indicate adequate fit of the model to the data. Compared with all other models, Model 7Ha had the highest CFI (.96), and AGFI (.93), and lowest RMSEA (.058), RMSR (.040), and BIC (−263.11) and was significantly better than Model 6Ha. However, inspection of the factor correlation matrix reveals an inadmissible parameter. The correlation between the Visual Working Memory and general ability factor exceeds 1.0. Therefore, within a hierarchical model with a general ability factor, seven second-order factors represent an overfactoring of the data.

Model 5Ha has the best fit statistics when excluding Model 7Ha. This is a hierarchical model with a first-order general ability factor and five second-order factors (i.e., Verbal Comprehension, Perceptual Reasoning, Working Memory, Processing Speed, and Memory). The fit statistics for Model 5Ha compared with Model 4Hb were the higher for TLI (.94) and AGFI (.92) and lower for RMSEA (.060), RMSR (.041), and BIC (−243.10). Model 5Ha shows statistically significant better fit to the data than Model 4Hb. Model 6Ha had similar fit indices as Model 5Ha; however, the fit improvement was not statistically significant. Of the Models excluding 7Ha, Model 5Ha has the best fit to the data.

Given that Model 7Ha had the best fit statistics but was inadequate due to the high correlation between the general ability factor and a second-order factor, the models were reanalyzed without a general ability factor but allowing correlations among the seven latent factors. Table 3 presents fit statistics for Models 2NHa-7NHa with all the specified factors as first-order factors. The results indicate that Model 7NHa has the best fit statistics, which is consistent with the results of the hierarchical model. However, in the nonhierarchical model, there were no inadmissible parameters. Therefore, Model 7NHa is the best model when not considering the impact of a general ability factor. By comparison, Model 7NHa had superior fit statistics relative to the Model 5Ha. Model 5Ha shows an adequate fit to the data but Model 7NHa is a good fit to the data with RMSEA values <.05 and CFI and TLI >.95. The nonhierarchical Model 5NHa does not have substantially higher goodness-of-fit statistics compared with the hierarchical model and has a BIC value five points higher than the hierarchical model;

**Table 2.** Confirmatory Factor Analysis Statistics With WAIS-IV and WMS-IV Subtests for 13 Hierarchical Models

| Model | $\chi^2$ | *df* | AGFI | RMSEA | RMSR | CFI | TLI | BIC | $\Delta\chi^2$ | $\Delta df$ | *p* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2Ha | 879.75 | 102 | .84 | .092 | .059 | .88 | .87 | 185.91 | | | |
| 3Ha | 656.67 | 98 | .88 | .080 | .048 | .91 | .90 | −19.96 | | | |
| 3Hb | 712.41 | 99 | .87 | .083 | .054 | .91 | .89 | 38.97 | | | |
| 3Hc | 672.37 | 101 | .87 | .079 | .053 | .91 | .90 | −14.97 | | | |
| 3Hd | 639.05 | 98 | .88 | .078 | .049 | .92 | .90 | −27.58 | | | |
| 4Ha | 503.69 | 98 | .90 | .068 | .049 | .94 | .92 | −162.95 | | | |
| 4Hb | 452.46 | 97 | .91 | .064 | .042 | .95 | .93 | −207.35 | | | |
| 5Ha | 409.93 | 96 | .92 | .060 | .041 | .95 | .94 | −243.10 | 42.53 | 1 | <.001 |
| 6Ha | 408.79 | 95 | .92 | .061 | .041 | .95 | .94 | −237.44 | 1.14 | 1 | .286 |
| 7Ha | 376.31 | 94 | .93 | .058 | .040 | .96 | .94 | −263.11 | 32.48 | 1 | <.001 |
| 5Hb | 484.91 | 97 | .90 | .067 | .042 | .94 | .93 | −174.89 | | | |
| 6Hb | 493.47 | 97 | .90 | .067 | .049 | .94 | .93 | −166.36 | | | |
| 7Hb | 548.78 | 96 | .89 | .072 | .055 | .93 | .92 | −104.25 | | | |

*Note*. WAIS-IV = Wechsler Adult Intelligence Scale–fourth edition; WMS-IV = Wechsler Memory Scale–fourth edition; AGFI = adjusted goodness-of-fit index; RMSEA = root mean squared error of approximation; RMSR = root mean square residual; CFI = comparative fit index; TLI = Tucker–Lewis nonnormed fit index; BIC = Bayesian information criterion. Statistical significance compares nested models of interest starting with Models 5Ha versus 4Hb and each subsequent model is compared with the previous model.

**Table 3.** Confirmatory Factor Analysis Statistics With WAIS-IV and WMS-IV Subtests for 10 Nonhierarchical Models

| Model | $\chi^2$ | *df* | AGFI | RMSEA | RMSR | CFI | TLI | BIC | $\Delta\chi^2$ | $\Delta df$ | *p* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2NHa | 879.75 | 103 | .84 | .092 | .059 | .88 | .87 | 179.11 | | | |
| 3NHa | 656.67 | 98 | .88 | .080 | .048 | .91 | .90 | −9.96 | | | |
| 3NHb | 712.41 | 99 | .87 | .083 | .054 | .91 | .89 | 38.97 | | | |
| 3NHc | 672.37 | 101 | .87 | .079 | .053 | .91 | .90 | −14.67 | | | |
| 3NHd | 652.48 | 99 | .88 | .079 | .049 | .92 | .90 | −20.97 | | | |
| 4NHa | 499.61 | 97 | .90 | .068 | .048 | .94 | .93 | −160.22 | | | |
| 4NHb | 435.21 | 95 | .91 | .063 | .041 | .95 | .93 | −211.02 | | | |
| 5NHa | 381.31 | 91 | .92 | .060 | .038 | .96 | .94 | −237.70 | 53.90 | 4 | <.001 |
| 6NHa | 301.06 | 86 | .93 | .053 | .031 | .97 | .95 | −283.95 | 80.25 | 5 | <.001 |
| 7NHa | 236.10 | 80 | .94 | .047 | .027 | .98 | .96 | −308.09 | 64.96 | 6 | <.001 |

*Note*. WAIS-IV = Wechsler Adult Intelligence Scale–fourth edition; WMS-IV = Wechsler Memory Scale–fourth edition; AGFI = adjusted goodness-of-fit index; RMSEA = root mean squared error of approximation; RMSR = root mean square residual; CFI = comparative fit index; TLI = Tucker–Lewis non-normed fit index; BIC = Bayesian information criterion. Statistical significance compares nested models of interest starting with Models 5NHa versus 4NHb and each subsequent model is compared with the previous model.

therefore, the nonhierarchical Model 5NHa was not evaluated further.

Model 5Ha adequately fits the data; however, additional variations of this model were evaluated to determine if the model fit could be improved. Exploratory factor analysis and an inspection of the modification indexes suggested that some additional subtests potentially load on multiple factors. Three additional variations of this model were evaluated with CFA. The first variation (Model 5Ha.1) includes the original cross-loadings with additional cross-loadings of Designs and Symbol Span with Perceptual Reasoning. The second variation (Model 5Ha.2) uses the original cross-loading and allows Matrix Reasoning to cross-load with Working Memory. The third variation (Model 5Ha.3) uses the original cross-loadings with additional cross-loadings of Logical Memory on Verbal Comprehension, Matrix Reasoning on Perceptual Reasoning, and Symbol Span on Memory. The fit statistics for these models are presented in Table 4. Model 5Ha.3 shows the best fit of all the models. This version of the five-factor model has RMSEA values <.05, AGFI = .95, and CFI and TLI >.95 indicating a very good fit to the data. Each of the models shows a statistical improvement in fit to the data. This indicates that Model 5Ha.3 is a significant improvement over all the other models. The fit data are very similar between Model 5Ha.3 and Model 7NHa.

Additional variations of Model 7NHa were explored in an attempt to improve the fit for this model. Unlike Model

**Table 4.** Confirmatory Factor Analysis Statistics With WAIS-IV and WMS-IV Subtests for Three Hierarchical Variations of Model 5Ha and Two Nonhierarchical Variations of Model 10

| Model | $\chi^2$ | *df* | AGFI | RMSEA | RMSR | CFI | TLI | BIC | $\Delta\chi^2$ | $\Delta df$ | *p* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5NHa | 381.31 | 91 | .92 | .060 | .038 | .96 | .94 | −237.70 | | | |
| 5Ha.1 | 371.61 | 94 | .93 | .057 | .039 | .96 | .94 | −267.81 | 38.32 | 2 | <.001 |
| 5Ha.2 | 323.28 | 93 | .94 | .052 | .037 | .96 | .95 | −309.41 | 86.65 | 3 | <.001 |
| 5Ha.3 | 278.60 | 93 | .95 | .047 | .030 | .97 | .96 | −354.02 | 131.33 | 3 | <.001 |
| 7NHa.2 | 259.05 | 83 | .94 | .049 | .029 | .97 | .96 | −305.55 | | | |
| 7NHa.1 | 237.56 | 81 | .94 | .046 | .027 | .98 | .96 | −313.44 | 22.95 | 3 | <.001 |
| 7NHa | 236.10 | 80 | .94 | .047 | .027 | .98 | .96 | −308.09 | 1.46 | 1 | .227 |

*Note.* WAIS-IV = Wechsler Adult Intelligence Scale–fourth edition; WMS-IV = Wechsler Memory Scale–fourth edition; AGFI = adjusted goodness-of-fit index; RMSEA = root mean squared error of approximation; RMSR = root mean square residual; CFI = comparative fit index; TLI = Tucker–Lewis non-normed fit index; BIC = Bayesian information criterion. All models are presented in order of complexity with each subsequent model more complex than the previous. Statistics represent the change in the model fit statistics over the preceding model.

5Ha.3, in which more cross-loadings appear to improve model fit, Model 7NHa cross-loadings showed relatively low relationship between the subtest and the latent factor. In particular, Visual Reproduction had a factor loading of .12 with the latent Perceptual Reasoning factor. Two additional variations of the seven-factor model were explored. The first variation (i.e., Model 7NHa.1) dropped the cross-loading of Visual Reproduction on the Perceptual Reasoning factor. The second Model (i.e., Model 7NHa.2) dropped all cross-loadings. The fit statistics for these additional models are presented in Table 4. Model 7NHa.1 shows the best fit of all the seven-factor models. This version of the seven-factor model has RMSEA values <.05, AGFI = .94, and CFI and TLI >.95 indicating a very good fit to the data. Model 7NHa.1 shows statistically better fit to the data than the less complex Model 7NHa.2. The additional cross-loading of Visual Reproduction on the Perceptual Reasoning factor (Model 7NHa) does not significantly improve the model fit compared with Model 7NHa.2. The fit data are very similar between Model 5Ha.3 and Model 7NHa.1 with the exception of lower BIC values for Model 5Ha.3.

Table 5 presents correlation coefficients for the latent factors of Model 7NHa.1. Overall, cognitive abilities are highly related. The Visual Working Memory factor correlates highly with most factors, particularly with Visual Memory. In previous models tested, Visual Working Memory correlated very highly with a general ability factor; therefore, it is not unexpected that it would correlate highly with many latent factors. In general, the correlations show a trend for abilities to correlate more highly with latent factors in the same modality (e.g., Auditory Memory correlates more highly with Verbal Comprehension than with Perceptual Reasoning) and with similar latent ability (e.g., Auditory Memory with Visual Memory). Figure 1 displays the factor loadings for Model 7NHa.1.

**Table 5.** Factor Correlations Seven-Factor Model (7NHa.1)

| Factors | VC | PR | PS | AWM | VWM | AM |
|---|---|---|---|---|---|---|
| PR | .73 | | | | | |
| PS | .48 | .67 | | | | |
| AWM | .69 | .76 | .68 | | | |
| VWM | .71 | .88 | .72 | .88 | | |
| AM | .71 | .60 | .52 | .68 | .82 | |
| VM | .54 | .81 | .54 | .64 | .96 | .81 |

*Note.* VC = Verbal Comprehension; PR = Perceptual Reasoning; PS = Processing Speed; AWM = Auditory Working Memory; VWM = Visual Working Memory; AM = Auditory Memory; VM = Visual Memory.

Figure 2 displays the factor structure for Model 5Ha.3. In this model, there are many more subtest cross-loadings compared with the seven-factor model presented in Figure 1. Working Memory, again, has a high correlation with general ability. Subsequently, most of the subtests within this factor have cross-loadings with other factors. At the factor level, this Model 5Ha.3 is more parsimonious than Model 7NHa.1; however, at the subtest level it is more complex.

Both Model 5Ha.3 with a first-order general ability factor and Model 7NHa.1 show good fit to the data. All the fit statistics are similar with a very slight improvement observed in BIC for the model with fewer factors. This would be expected given BIC favors more parsimonious models. Raftery (1993) provides guidelines for comparing BIC values between models. Differences between BIC values of more than 10 points would strongly favor one model over another (Raftery, 1993). Using this guideline, Model 5Ha.3 would be considered a better fit to the data than Model 7NHa.1; however, Model 7NHa.1 has better fit statistics for CFI, RMR, and RMSEA. Overall, both the five- and seven-factor models appear to fit the data well.

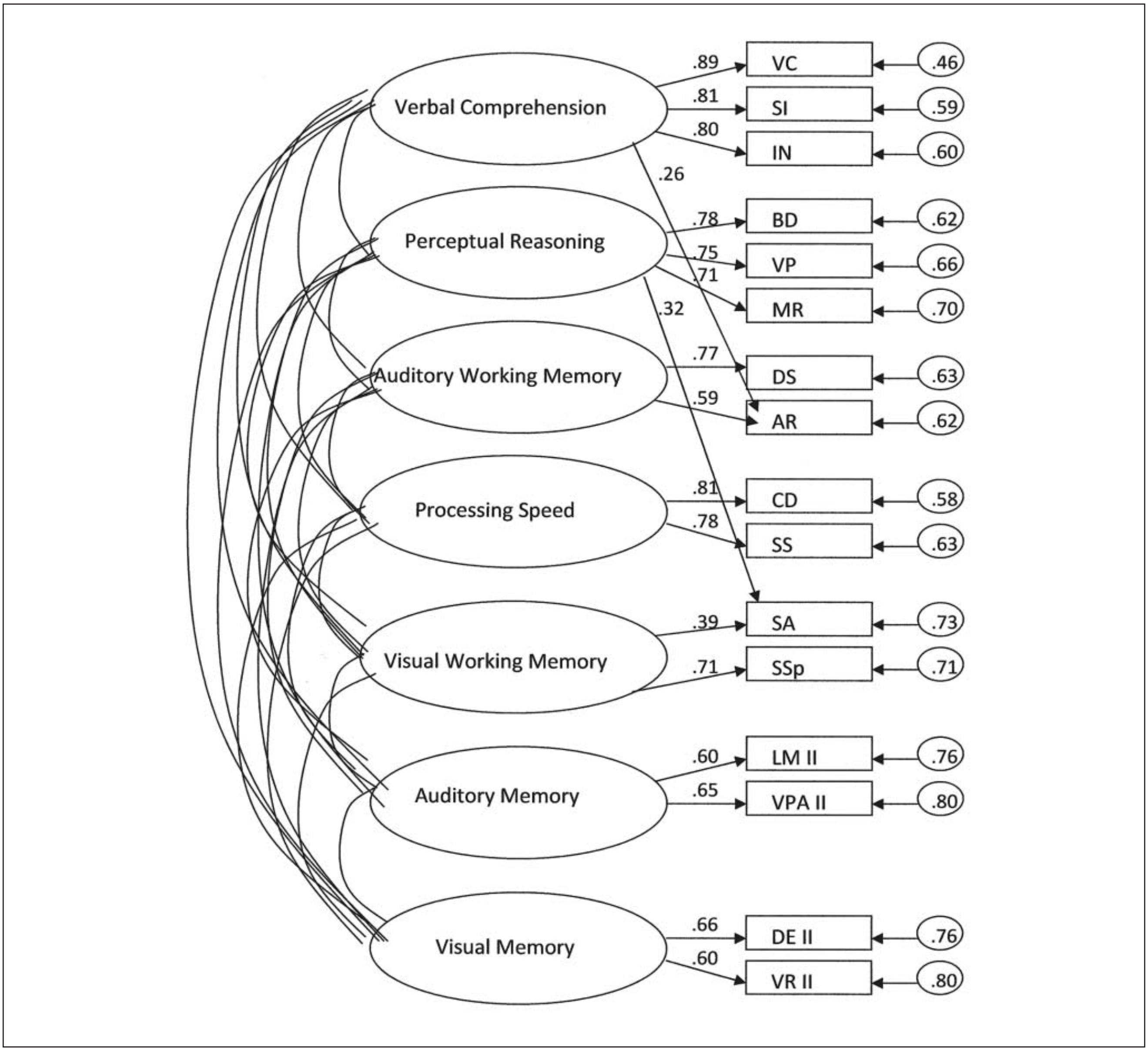


**Figure 1.** Seven-factor model (7NHa.1) of WAIS-IV/WMS-IV subsets
*Note***.** WAIS-IV = Wechsler Adult Intelligence Scale–fourth edition; WMS-IV = Wechsler Memory Scale–fourth edition; VC = vocabulary; SI = similarities; IN = information; BD = block design; VP = visual puzzles; MR = matrix reasoning; DS = digit span; AR = arithmetic; CD = coding; SS = symbol search; SSp = symbol span; LM II = logical memory delayed; VPA II = verbal paired associates delayed; DE II = designs delayed; VR II = visual reproduction delayed.

## Discussion

The current study evaluated the latent factor structure of the combined subtests from the WAIS-IV and WMS-IV. Factor analytic studies of previous editions of the tests found support for a six-factor model (Bowden et al., 2004; Tulsky et al., 2003). The latent factor structure in the previous edition included Verbal Comprehension, Perceptual Reasoning, Working Memory, Processing Speed, Auditory Memory and Visual Memory. The Working Memory factor in the previous editions was composed of both auditory and visual working memory subtests. Within the six-factor model, many subtests cross-loaded on more than one factor (Tulsky et al., 2003). Therefore, many subtests, particularly

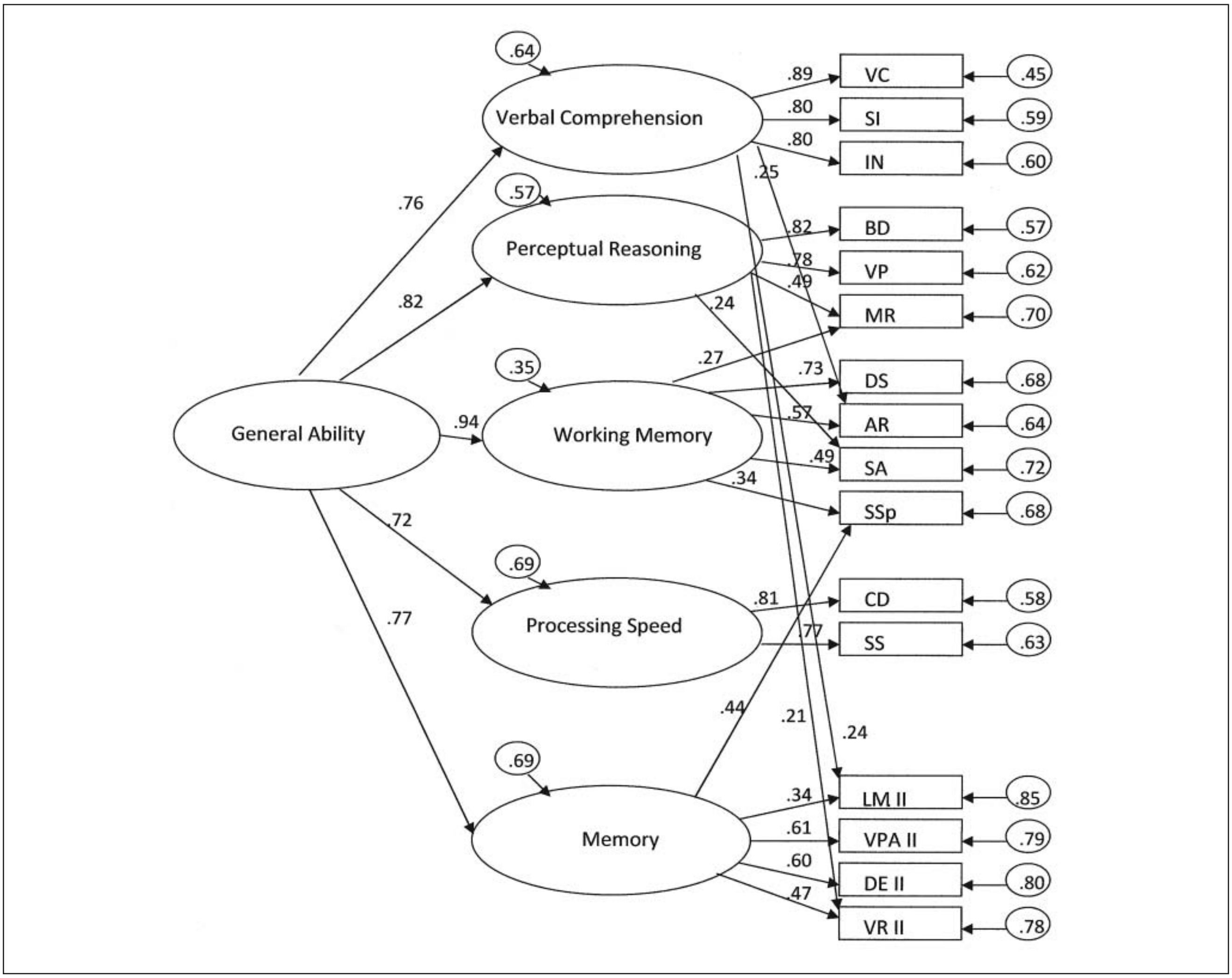


**Figure 2.** Five-factor model (5Ha.3) of WAIS-IV/WMS-IV subsets

*Note***.** WAIS-IV = Wechsler Adult Intelligence Scale–fourth edition; WMS-IV = Wechsler Memory Scale–fourth edition; VC = vocabulary; SI = similarities; IN = information; BD = block design; VP = visual puzzles; MR = matrix reasoning; DS = digit span; AR = arithmetic; CD = coding; SS = symbol search; SSp = symbol span; LM II = logical memory delayed; VPA II = verbal paired associates delayed; DE II = designs delayed; VR II = visual reproduction delayed.

memory, working memory, and perceptual reasoning measures, show a complex relationship to the latent cognitive factors.

The combined WAIS-IV and WMS-IV batteries yield 10 index scores: Full-Scale IQ, Verbal Comprehension, Perceptual Reasoning, Working Memory (i.e., Auditory), Processing Speed, Visual Working Memory, Auditory Memory, Visual Memory, Immediate Memory, and Delayed Memory. The index structure of the WAIS-IV/WMS-IV is based on the six-factor model proposed by Tulsky and Price (2003) and Tulsky et al. (2003) with the exception that auditory and visual working memory subtests have been separated into different indexes. In the previous editions, it was not possible to have a separate Visual Working Memory Index because only one subtest measured that construct. The inclusion of Immediate and Delayed Memory indexes represents clinical practice and differential sensitivity to clinical samples with known memory impairment (Wechsler, 2009) rather than being based on a factor analytic approach to construct validation (Tulsky et al., 2003).

It was hypothesized that having two visual working memory subtests may result in the working memory factor being split into two modality specific measures of working memory. Therefore, a seven-factor solution, including Verbal Comprehension, Perceptual Reasoning, Working Memory, Processing Speed, Visual Working Memory, Auditory Memory, and Visual Memory, and a general ability factor with subtests cross-loading on multiple factors was hypothesized to best fit the data. Cross-loadings were based on previous research and exploratory factor analysis. The delayed memory subtests from the WMS-IV were used to avoid potential model specification errors related to the statistical dependency caused by including both immediate and delayed scores in the same factor analysis.

Initial results for the seven-factor hierarchical model (Model 7Ha) produced model specification errors because of a correlation between visual working memory and general ability greater than 1.0. Of the hierarchical models, a five-factor model that collapses the visual and auditory measure for working memory and for memory into single factors best fit the data. However, good model fit was obtained for the seven-factor model (Model 7NHa) without a general ability factor. Subsequently, the fit for the seven-factor model without a hierarchical general ability factor was better than the initial evaluation of the five-factor model (Model 5Ha). Reevaluation of the five-factor model by increasing the number of subtest cross-loadings, improved the overall fit of that model (Model 5Ha.3) and resulted in nearly identical fit statistics between the seven-and five-factor models.

Finding two models with similar fit statistics was not the expected outcome. However, given that multiple models for the WMS-III and WAIS-III have been reported (Burton et al., 2003; Kaufmann et al., 2001; Keith et al, 2006; Wechsler, 1997; Wilde et al., 2003), it is not totally surprising that competing models could have good fit to the data. Ultimately, the best model will be the one that is replicated in multiple studies and across different types of examinees. When considering the models together, it provides very good support for the current Index structure of the combined WAIS-IV/WMS-IV. The combined factor structure supports some overlap in the constructs measured across the batteries (i.e., working memory) but primarily shows the distinctiveness of the constructs measured across the two batteries. In the five-factor model, we find support for a general ability measure that corresponds to Full-Scale IQ on the WAIS-IV and for combining visual and auditory memory measures, which is presented in the WMS-IV as the Delayed Memory Index. The seven-factor model supports splitting working memory and memory into separate auditory and visual factors. The only index of the WAIS-IV/WMS-IV not supported in the models is the WMS-IV Immediate Memory Index since no immediate subtests were used in the analysis.

No matter which model is applied, the WAIS-IV/WMS-IV subtests are complex measures related to a variety of cognitive functions. If a simplified factor structure is used then the subtests split on more factors. If a more complex factor structure is applied, then there are relatively high correlations between the factors. These results are consistent with the concept that tests (e.g., memory and working memory) are affected by abilities in other cognitive domains (Heilbronner, 1992; Wechlser, 2009; Weiss, Saklofske, Prifitera, & Holdnack, 2006) depending on how the constructs are measured (e.g., verbal comprehension effects on logical memory, perceptual reasoning effects on visual reproduction). Scores achieved on these tests must be interpreted in consideration of the influence from these other cognitive abilities.

Working memory ability has a significant influence on overall cognitive functioning. In the hierarchical seven-factor model, visual working memory correlated >1.0 with general ability. And, of all the latent factors in the five-factor model, working memory had the highest correlation with general ability. This is consistent with previous studies showing high association between working memory and general ability (Ackerman, Beier, & Boyle, 2005; Colom, Abad, Rebello, & Shih, 2005) or more specifically to fluid reasoning (Kane, Hambrick, & Conway, 2005). Working memory functioning may have a reciprocal influence on cognitive performance. The working memory scores are influenced by the cognitive context in which they are measured (e.g., verbal or perceptual) while also affecting the individuals' ability to do other complex reasoning tasks. This is illustrated by the cross-loading pattern in the five-factor model: Matrix Reasoning, a fluid reasoning test, cross-loads with Working Memory factor, whereas Spatial Addition, a working memory test, cross-loads with Perceptual Reasoning. It is reasonable to expect that complex problem solving would require the use of working memory.

In all the models, the most stable latent factors were Verbal Comprehension, Perceptual Reasoning, and Processing Speed. Verbal Comprehension and Perceptual Reasoning are well-established latent factors in the Wechsler scales. Tests in those domains are selected based on their association with the latent factor. Since the processing speed factor is measured only in the visual domain, there are no additional measures of the same construct that have variance associated with a different cognitive modality (e.g., auditory). The interpretation of these subtests and indexes is relatively straightforward, as only Matrix Reasoning cross-loaded with another factor and only in the five-factor model. In consideration of the high correlation between working memory skills and general ability, it may be prudent to consider the constraints placed on intellectual performance in the presence of low working memory ability.

There are direct clinical implications derived from the results of this study. The five-factor solution indicates that the auditory and visual working memory and memory measures should not be considered in isolation. On the WMS-IV, this would indicate a focus on using the Immediate and Delayed Memory Indexes, which are composed of measures from each of the auditory and visual memory subtests. Only one working memory index (e.g., WAIS-IV WMI or WMS-IV WMI) would need to be used as they would provide similar information about the examinees working memory functioning, and WAIS-IV Full-Scale IQ would also be evaluated to provide additional information in regards to overall cognitive functioning. When using the five-factor model, an emphasis on interpreting subtest level variability, as related to performance on the five indexes would be necessary to account for the influence of multiple cognitive skills on memory and working memory subtests. However, there is no direct method for evaluating subtests strengths and weaknesses in the context of the influence of performance on different index scores. Therefore, the clinician must make a judgment about the reasons for particular low scores (e.g., poor memory functioning vs. poor visual–spatial abilities).

The seven-factor model (Model 7NHa.1), although more complex in terms of the number of index scores evaluated, does not require significant additional evaluation of subtest variability. Although two subtests cross-load, the influence of these cross-loadings may be examined at the index level with the application of contrast scores (Wechsler, 2009). The contrast scores provide an estimation of the variance in one test controlling for a precursor cognitive ability (e.g., auditory memory controlling for verbal comprehension ability). Subsequently, it is possible to determine if a low score on one index is still considered a low score when you control for performance in another cognitive domain. The index scores and relevant contrast scores are the primary level of interpretation when the seven-factor model is applied.

In Model 7NHa.1, we observe a high correlation between visual memory and visual working memory. This high correlation is due to common cognitive abilities (i.e., remembering visual details and spatial information across different periods of time) and also to method variance (e.g., Designs and Spatial Addition both use the same memory grid). In addition, having better working memory for visual information may facilitate encoding of that information into long-term memory stores. In a healthy population, it would be expected that examinees would have similar scores on these indexes; however, in clinical populations where deficits in delayed memory relative to working memory are present, these indexes may dissociate. Performance on the Visual Memory Index controlling for performance on the Visual Working Memory index is evaluated using the specific WMS-IV contrast score for this comparison.

The selection of which model to apply would be based on clinical hypotheses derived from the diagnostic and intervention questions that resulted in the need for evaluation. In some clinical samples, impairments in delayed recall may be more prominent than differences between auditory and visual memory. Whereas in other clinical samples the distinction between visual and auditory memory is more important than immediate or delayed memory. In some cases, there may not be sufficient data to select a specific model and all index scores may need to be evaluated.

There are a number of limitations to the current work. The two models identified in this study should be cross-validated in another large sample of healthy adults and in specific clinical populations. It is necessary to determine if either model is superior to the other, to determine if an alternate model may be superior to the ones reported here, and to identify the best models for various clinical samples. In particular, there may be specific clinical samples in which separate immediate and delayed memory factors can be identified. Also, the model needs to be verified for its applicability to specific subsets of examinees within the general population (e.g., low educational achievement, minority groups, age). This study is limited by using only the WAIS-IV and WMS-IV in the analysis. Including additional memory and working memory measures in the analysis may yield more clearly defined factors or identify a single superior model.

## Authors' Note



## Declaration of Conflicting Interests

The authors declared a potential conflict of interest (e.g., a financial relationship with the commercial organizations or products discussed in this article) as follows:

Dr. Holdnack is a Senior Research Director with Pearson and Dr. Zhou is manager of psychometric services with Pearson, which is the publisher of the WAIS-IV and WMS-IV. Drs. Larrabee, Millis, and Salthouse do not have a conflict of interest to declare.

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