The second factor is fairly straightforward in interpreting. It consisted of both the Rhomberg and Gait and Station tests. As pre-specified in the Sensory-Motor Manual, these two tests share the commonality of being subcortical motor tests. Thus, this factor was interpreted to be representative of subcortical motor or a gross-motor factor.

The third factor was dominated by tests of Simultaneous Localization (SL). However, this factor reveals an interesting fact about the Simultaneous Localization test. The three highest loading tests on this factor were simple SL tests that only required the recognition of being touched on the right, left, or both hands; whereas the other SL tests involved the hand and cheek. Three other SL tests loaded on this factor but had higher loading on a different factor. Palm Writing Letters and Finger Identification also had loadings on this factor. Taken together, this factor seemed to represent a sensory factor primarily involving the hands. This includes identification of the hands or fingers as well as identifying letters drawn on the hands. Similarly, the fourth factor was a mix between hand and cheek tests. The test loading on the third factor were primarily the other SL tests along with Palm Writing Letters.

The fifth factor consisted of all Visual Confrontation tests (left, right, and both). The sixth factor consisted of all Auditory Perception tests (left, right, and both). A joint loading was found for the seventh factor. The seventh factor consisted of the Coordination Finger to Nose test and the SL Left Hand Left Cheeck and SL Right Hand Right Cheek tests. The commonality among these tests is the involvement of both the hands and the cheek. More generally, this factor most likely represents a prosagpagnosia factor of the head region. Prosagpagnosia is a neuropsychological term that is indicative of bodily awareness.

The eighth factor is interesting in that it is represented by tests that involved cross-lateral movements or cross-lateral sensory identification. This factor is represented by the Movement test and the SL Left Hand Left Cheek and SL Right Hand Right Cheek. These tests involve either moving the arm across the body midline or simultaneously recognizing sensory input on the right and left side of the body. This factor is interesting in that tests that have a functional commonality (i.e. involve cross laterality) have a higher relation regardless if the tests primarily engage sensory or primarily engage motor processes.

The ninth factor is solely represented by the Coordination Hand/Thigh test. It appropriately shows negative loadings since it is the only test where higher scores indicate better performance. The tenth factor is represented by Grip Strength. The eleventh factor was solely represented by Finger Tapping and the twelfth factor was solely represented by Near Point Visual Acuity.

An additional observation can be made about the factors extracted. Many of the factors extracted were specific to one factor. That is, many of the tests loaded solely on one factor and no other factor. This may suggest many of the tests are narrow and encompass a very specific type of ability. In Carroll's theory, these tests would most likely be placed at the Stratum I level. This, however, is not surprising since many of these tests were developed for the very specific purpose of identifying very specific areas of brain dysfunction. For example, the

Finger Tapping test was developed to assess and diagnose damage in the motor strip of the frontal lobe (Halstead, 1947). In this study, the Finger Tapping test primarily loaded on a single factor that was not shared by any other test. Carroll (1993) also studied similar tests and found a single factor that he called Wrist-Finger Speed. Tests loading on this factor are usually low in complexity and do not require a significant amount of cognitive processing to execute. This may suggest a fairly general principle between neuropsychological tests and CHC classification in that tests that measure narrow abilities may rely on more localized areas of the brain and may be more sensitive to damage in a localized areas; whereas, tests that rely on numerous cognitive processes (reasoning, memory, etc.) may be more sensitive to global brain damage and less sensitive to localized damage. Tests that require numerous cognitive abilities or depend on the coherence of numerous cognitive processes, may be more resilient to the effects of localized brain damage; whereas, tests of narrow abilities that require only a few cognitive abilities or cognitive processes may be more localized in the brain and, thus, more susceptible to localized damage. This may account for the neuropsychological findings that general intelligence is often spared in individuals with brain damage, yet certain tests of the Halstead-Reitan, such as the Finger Tapping Test, are known to be sensitive to brain damage in certain areas of the brain. In essence, “g”, the highest stratum of CHC theory, involves numerous cognitive processes, and thus numerous areas of the brain, and narrow abilities, the lowest stratum of CHC theory, involve few cognitive abilities and fewer areas of the brain. Of course, more research is needed to explore this hypothesis.

Section B

Introduction

Section B of Study 1 consisted of an iteratively based model-building search that incorporated theoretical and statistical (from section A) aspects of the SMB. This section consisted of several confirmatory factor analyses on the SMB. The models were derived from a mixture of empirical results from section A of Study 1 and theoretical guidance from the SMB manual (Dean & Woodcock, 2000). Several competing models were developed and compared based on fit indices and loading parameters. Indices of parsimony were also taken into consideration in judging the best fitting model. The model that best fit the data was selected to be used in Study 2.

Method

Participants. Participants from Study 1 section A were used for this analysis.

Measures. Sensory Motor Battery: see description in section A.

Procedure. An initial analysis was conducted that estimated fit statistics for all size models was also performed as an adjunct to this section. This analysis estimated the fit statistics for models with factors of 1-12. This analysis will be used as additional support for selecting a factor structure of the SMB. This analysis was performed with MPLUS (Muthen & Muthen, 1998).

AMOS (4.01) (Arbuckle & Wothke, 1999) was used for the confirmatory factor analysis. This software was used to analyze the data and to derive model fit indices. The initial scores for the SMB were in raw scores. Since raw scores are not corrected for age, the scores were regressed on age in months and the residuals from this regression were saved as a separate variable in standardized form. Residual scores represent the test variance with age variance partialed out and provide more accurate information than standard scores (Jensen & Sinha, 1993).

The confirmatory models differed primarily on either an emphasis of theory or from an emphasis on the exploratory factor analysis results (section A). For example, the first model tested was taken from a strict interpretation of the theoretical model described in the Sensory Motor Battery Manual (Dean & Woodcock, 2000). Another model was developed to closely correspond to the factor analysis (empirical evidence). A third model was a synthesis of the theoretical based and the empirically based models. For this model, the factors selected via the factor analysis were synthesized with the theoretical basis of the Sensory Motor Battery a model that was both a mixture of theory and empirical findings. Thus, the third model was, in essence, the theoretical model informed by the factor analysis.

Model Building: Several plausible models of the SMB were developed using empirical results from the factor analysis in Section A in Study 1 and theoretical specifications of the SMB. The developed models are chunked into 3 categories. The first category is composed of models that are primarily theory based. The second category is composed of models that are primarily empirical based. The third category is composed of models that are mixed between theory and empirical evidence. There is considerable overlap among these categories, and they are used solely for convenience in organizing the results. Although many other model variations could have been tested, the present study only used models with some link to theoretical or empirical evidence from past studies and findings of the current study.

In developing the first group of models, more emphasis was placed on theory rather than empirical evidence. Different models were developed based on variations in the SMB theory. As described in the manual, the SMB is primarily composed of sensory and motor tests (Dean & Woodcock, 2000). The sensory tests are of two categories: simple and complex. Simple sensory tests are that of Visual Confrontation, Auditory Perception, Naming Pictures of Objects, Finger Identification, and Lateral Preference. Complex sensory tests consisted of Palm Writing, Simultaneous Localization, and Object Identification. Motor tests were also described in two categories: cortical and subcortical. Cortical motor tests delineated by theory are Mime Movements, Finger Tapping, Grip Strength, Coordination, Construction, and Expressive Speech. Subcortical motor tests described by the SMB theory are the Rohmberg and Gait and Station tests. Based on this description, a four-factor model (Simple Sensory, Complex Sensory, Motor Cortical, Motor Subcortical) was constructed to account for the variance on the SMB. The first model (M1) was a correlated two-factor model that consisted of one sensory factor and one motor factor (see Figure 3). This was based on a very general variation in the SMB theory. Another model was tested (M2) that specified three factors (see Figure 4). This model was similar to the two-factor model but incorporated some of the results of the factor analysis in

Section B that suggested the Gait and Station and Romberg tests loaded on a single factor to a fairly high degree. The factors in the three-factor model contained a Sensory, Motor, and Sub-Cortical Motor (Gait and Station Tests and Rhomberg Tests) factor. A fourth model (M3) was then developed (see Figure 5). Due to estimation difficulties with a four-factor model with all factors correlated, the variance for the simple sensory factor was specified to equal 1. This model was believed to be the best representation of the SMB as described by the SMB manual (Dean & Woodcock, 2000).

A second group of models were constructed that placed more emphasis on the empirical results of the factor analysis in Section B. All tests that loaded on a factor in the factor analysis were modeled as an indicator of a latent variable. The first model of the factor based models (M4) placed a greater emphasis on the factor analysis results of section A (Figure 6). Only factors that had plausible factor interpretations were used a in the confirmatory model and the criteria for factor retention was more inclusive than exclusive. A total of twelve factors were specified. Some reliance on theory was needed to specify loadings for tests that did not load on any factor in the factor analysis. Additionally, some reliance on theory was needed since most factor analyses will leave residual tests or tests that load on multiple factors. The second factor based model (M5) was identical to the first model but relied on modification indices to determine correlations among the factor constructs (Figure 7). The Modification Index was used to determine correlations among the latent variables and any other variable that improved the model fit. The Modification Index (M.I.)

is a univariate version of the Lagrange Multiplier which is expressed as a chi-square statistic with one degree of freedom (Kline, 1998). The M.I. is an estimate of the decrease in chi-square if a particular parameter was estimated. For this study, a chi-square distribution table was used to determine the significance of a chi-square with 1 degree of freedom and the $p < .05$. This significance value is 3.841 (Hogg & Tanis, 1997). Although this rule is statistically sound, it cannot be solely relied upon due to the ease of M.I. to meet this criterion. In most analyses, nearly all M.I. meet this criterion. Although this rule was taken into consideration in choosing which model change to make, only model changes with that made substantially large changes in the chi-square statistic were applied to the model. After each change, the model was re-estimated and the modification indices were re-evaluated. In total, 8 correlations among factors were implemented based on modification indices.

The third group of models were developed that incorporated both theoretical and empirical evidence equally and attempted to represent a synthesis of the theoretical and empirical based models. The first model (M7) attempted to account for the numerous simple factors described by the factor analysis and also account for the proposed theory described in the SMB manual (Figure 8). This model extends the hierarchical structure of the SMB by extending the measurement model, as suggested by the factor analysis, and including the structural model outlined by the theory. A second model (M8) identical to the above described model was developed that was further refined by modification indices (Figure 9). Only plausible and substantial changes were made based on the modification index (Long, 1983). Changes based on the modification index were Modification indices were considered, including changes for correlated errors.

Results and Discussion (Section B, Study 1)

Table 7 displays the results of estimating numerous models with various factor number specifications. Estimates from this table suggest fit indices reach an acceptable level at approximately 7 or 9 factors. Although these estimates were used as a preliminary evaluation of model fit, the table does provide evidence that multiple factors are needed to account for the variance in the SMB.

Each confirmatory model and the corresponding parameter weights can be found in Figures 3, 4, 5, 6, 7, and 8. These figures illustrate the measurement and structural models used to model the SMB data. The parameter weights on the model are the standardized coefficients. Model fit statistics can be found in Table 8.

The fit indices can be compared for each cluster of models (theory based, factor based, and theory/factor based) as well as across clusters. In examining the fit indices for all models, it can be concluded that no model fits the data extremely well. For the theory based models, the models fit equally well with the exception of the three-factor model. The RMR index suggested the three-factor model fit the data better than the two and four factor model. In comparing the theory based models to the empirically based models,

The second group consisted of factor based models. In developing these models, more emphasis was placed on the empirical evidence of the factor analysis. Like the theory based models, no model fit the data extremely well. The factor based model with correlated factors fit the data slightly better than the model with no correlated factors. In general the factor based models fit the data better than the theory based models.

The third group contained a synthesized model of theory and factor based model (see Table 8). In examining the modification indices, it was noted that of all tests, Gait and Station Toe to Heel was most suggestive of having additional shared variance with other tests than just the tests of the Sub-Cortical Motor factor.

The factor analysis of the SMB, although not conclusive, suggested the SMB cannot be a) described just by sensory and motor constructs or b) there is a higher-order factor that accounts for the correlations between sensory and motor tests. Additionally, it suggested a high degree of overlap between tests designated and sensory and tests designated as motor tests. Many of the larger factors extracted from the SMB data consisted of a mixture of sensory and motor tests. The majority of the smaller factors extracted from the SMB were mainly test specific. These factors may indicate the tests are similar to what Carroll referred to as Stratum 1 abilities. Of the small factors that were extracted, the interpretation of the factors was rather clear since the smaller factors consisted of tests from the same subtests. In most cases, identical tests that included a right and left of midline distinction, loaded on the same factor.

The factor analysis corresponded with the proposed theory of the sensory-motor battery in suggesting there were more than just sensory and motor factors at work. The confirmatory factor models, varying by emphasis of theory or empirical evidence, in conjunction with the factor analysis suggested there is a least one hierarchical factor of among the sensory-motor tests. The proposed theory of the SMB fits the data significantly better if the proposed factors are modeled as higher order factors, rather than just a first-order factor. However, when the 4 factors proposed by theory are modeled as 4 higher order factors, the model does fit the data significantly better but is equal to an identical model with only a single higher order factor. Additionally, the correlations between the model with multiple higher order factors were in the range of .8 to .99. This is suggestive that the higher order factors are indistinguishable and are better modeled by a single higher order variable. As such, the best fitting model for the SMB was chosen to be a model with multiple first-order factors and a single higher order factor. Therefore, this model was used in the joint confirmatory factor analysis of Study 2.

Study 2

Introduction

The purpose of the second study was to examine the factor structure of the SMB derived in Study 1 in relation to the CHC theory of human cognitive abilities. For this purpose a joint confirmatory factor analysis was performed. The primary goal of this analysis was to estimate the parameters between the SMB constructs and the CHC constructs. Although fit indices are reported for the model, primary focus was on the standardized coefficients of the model. Fit indices were still examined to ensure identification and proper estimation of the model. Since this study was addressing the suitability of sensory/motor constructs being included in the CHC model, a model was developed that estimated the path coefficient between "g", the broad abilities of the CHC model, and between the highest order SMB construct. As such, the SMB construct was modeled as if it were an additional CHC broad ability. This model was used to examine the relationship between the third stratum variable of the CHC model (*g*) and the SMB.

Method

Participants. Participants for this study were 411 individuals from a clinical sample. Each participant was administered the SMB followed by the Woodcock-Johnson Revised Tests of Cognitive Ability. Test administration was completed by qualified examiners with extensive experience in test administration. The sample consisted of a broad age range (Age 3 to 90) with a mean age of 33.47 (sd = 25.88). The sample was equally balanced for gender (male= 201, female= 210). The ethnic proportions of the sample were: White= 92%, Black= 2.7%, Asian= .5%, Native American= .5%, and Other= 1.2%.

Measures. The SMB was used in conjunction with an instrument representative of CHC theory. The CHC theory was operationalized by the Woodcock-Johnson-Revised Tests of Cognitive Abilities (WJ-R). The Woodcock-Johnson– Revised Test of Cognitive Abilities (WJ-R) is based on the CHC theory of cognitive abilities. It consists of eight broad abilities that are each measured by two subtests.

WJ-R CHC abilities

Short-term Memory. Short-term memory (Gsm) is a critical component of most cognitive activities and is measured by WJ-R tests Memory for Names and Visual-Auditory Learning. Gsm is defined as the ability to hold information in conscious awareness and then use it within a few seconds. A classic example of this ability is remembering a telephone number long enough to dial it. Among the consequences of a short-term memory deficit is difficulty in remembering just imparted instructions or information. Most available tests of short-term memory measure the span of auditory awareness.

Chrystallized Intelligence. (Gc), also called Comprehension-Knowledge in the WJ-III, represents the breadth and depth of knowledge including verbal communication, information, and reasoning when using previously learned procedures. A patient with a verbal-conceptual deficit may display a lack of information, language skill, and knowledge of non-automatic procedures. Gc is measured by Picture Vocabulary and Oral Vocabulary in the WJ-R.

Visual-spatial thinking (Gv) includes spatial orientation and the ability to analyze visual stimuli. Patients with Gv deficits may demonstrate poor spatial orientation, misperceive object-space relationships, have difficulty with art, and difficulty with using maps.

Auditory Processing (Ga) is the ability to analyze and synthesize auditory stimuli. This ability does not include understanding of language which is part of verbal-conceptual knowledge (Gc). Patients with Ga deficits may demonstrate speech discrimination problems and failure in recognizing sounds. This is measured by Incomplete Words and Sound Blending in the WJ-R.

Long-Term Storage-Retrieval (Glr) is the ability to store information and to retrieve it later through association. Note that this ability does not represent the knowledge itself but rather the ability to store and to consciously search for relevant information. For example, if you were asked, "What do people usually wear on their feet?," you would probably reply promptly with an answer such as, "shoes or socks." This is an example of direct recall from the Gc store of acquired knowledge. If, on the other hand, you were asked, "when was the last time you wore the pair of shoes and socks you are wearing now?," you may need to think about the question before you could provide an answer. That type of thinking is an example of long-term storage-retrieval. Be aware that in some professional literature the body of stored information is referred to as "long-term memory" or "remote memory." These terms should not be confused with the thinking ability called here "long-term storage-retrieval". Patients with Glr deficits may demonstrate difficulty in fluently recalling relevant information and in learning and retrieving names. Glr is measured by Memory for Sentences and Memory for Words in the WJ-R.

Fluid Reasoning (Gf), is defined as the ability to reason, form concepts, and solve problems that often include unfamiliar situations or procedures. It is manifested in the reorganization, transformation, and extrapolation of information. We often associate Gf ability with clever solutions to novel problems. Patients with Gf deficits may demonstrate a difficulty in generalizing rules, forming concepts and seeing implications. Gf deficits may also underlie some social/emotional problems. Gf is measured by Analysis-Synthesis and Concept Formation in the WJ-R.

Processing Speed (Gs)is the ability to perform automatic or very simple cognitive tasks rapidly. Its role in the cognitive system may be likened to a valve in a water pipe. If the valve is open, flow is at a maximum; if the valve is partially closed, flow is reduced. One consequence of a processing speed deficit is that it takes more time for a patient to complete simple cognitive tasks. Slow Gs, however, also exerts a limiting influence on complex task processing by slowing the cycle time, thus producing inefficiency and increasing time from initiation to completion of a cognitive activity. Most people would obtain nearly perfect scores on a test of processing speed if given enough time. Typical speed tests are further characterized by the examinee being under pressure to maintain focused attention. Gs is measured by Visual Matching and Cross Out in the WJ-R.

The WJ-R was standardized with over 6,000 participants that included preschool children as well as elderly adults. Research evidence suggests the constructs measured by the WJ-R adequately represent CHC theory and the WJ-R contains a number of broad abilities that are not measured by other contemporary cognitive measurements (Woodcock, 1990). Specific information on validity and reliability estimates for each WJ-R subtest can be found in the WJ-R Technical Manual (McGrew, Werder, & Woodcock, 1991). In general, reliability estimates for tests on the WJ-R range from good to excellent.

Procedure. CHC theory will be operationalized and measured by the WJ-R Tests of Cognitive Ability. Fourteen subtests from the WJ-R will be included in the analysis. The CHC model to be tested will consist of these 14 subtests grouped together into broad factors. Each broad ability (Stratum II) will be estimated with at least two WJ-R subtests. The hierarchical model of the SMB was used in the joint confirmatory factor analysis with the CHC model and was chosen based on the results of Study 1. Few hypotheses were available to guide this analysis. Therefore only the most broad associations between the two models were tested. These associations were the relationships between the broadest factors of the SMB and the broadest factor of the CHC model. This resulted in a model that specified a relationship between the broad Sensory/Motor factor and the "g" factor from the CHC model. Although many other factors and relationships could possibly be tested, more background research on specific broad abilities and sensory-motor functioning is needed for the development of apriori hypotheses.

SPSS 9.0 (1999) was used to analyze all demographic information and descriptive statistics. AMOS (4.01) was used for the confirmatory factor analysis. This software will be used to analyze the data and to derive model fit indices. All variables used in the analysis were initially screened for outliers and data entering errors. The initial scores for the SMB were in raw scores and the WJ III scores were in W-score form. Since raw scores are not corrected for age, raw SMB and W scores were regressed on age in months. The residuals from this regression were saved as a separate variable in standardized form. Residual scores represent the test variance with age variance partialed out and provide more accurate information than standard scores (Jensen & Sinha, 1993). This procedure was identical to the procedure used in Study 1. Additionally, a linear trend-at-point data interpolation procedure was used to replace missing values. This procedure replaces missing values by regressing the existing series on an index variable scaled 1 to n. Missing values are replaced with its predicted values.

Results and Discussion

The specified model provided an estimate of the path coefficient between the higher-order factor of the SMB and the higher-order factor of the CHC model (*g*). No problems were reported in the model estimated output and the model was fitted within 20 iterations. Although fit indices were less important in this study than the previous study, they were still examined for any abnormalities in model estimation and to compare the reduction in fit for not specifying a path between the SMB and the CHC model. No abnormalities in model fit were indicated by the fit indices. The results of the joint confirmatory factor analysis of the hierarchical model of the SMB and the CHC model produced a standardized path coefficient of .82, and an unstandardized path coefficient of .73. The standardized path coefficient is comparable to other coefficients of broad abilities in the CHC model. Specifically, the standardized path coefficient for the broad abilities were: Glr (.84), Gsm (.82), Gs (.91), Ga (.93), Gv (.98), Gc (.93), and Gf (.95). Constructs of subcortical motor functioning were also estimated. Similar to the model in Study I where subcortical motor constructs were only moderately related to other constructs, the standardized path coefficient between “g” and the subcortical construct was .54.

Additionally, a chi-square difference test was performed to examine possible decrements in model fit as a result of specifying a path between "g" and SMB constructs. The chi-square difference test is the difference between chi-square values of two hierarchical models with its degrees of freedom equaling the differences between the two respective values (Keith, 1998). The chi-square value for the model without a path between "g" and SMB is X^2(6219.23, df = 1811). The chi-square value of the model with a path between "g" and SMB is X^2(5875.63, df = 1810). A chi-square difference tests yields X(1, N = 411) = 343.60, p < .00.

The findings from both of these analysis suggests a fairly large statistical relationship between the higher-order factor of the SMB and the higher order factor of the CHC model and low to moderate relationships between the sensory and motor factor and the CHC broad abilities. The estimation of the standardized coefficient between the "g" factor and the higher-order sensory-motor factor was not only significant but was at a magnitude comparable to other broad abilities within the CHC model. Although there were no apriori hypotheses to guess whether or not a significant correlation would be found between these two constructs, the magnitude of the correlation was rather surprising. The support for a relationship between cognitive abilities and sensory-motor tests was strengthened with the chi-square analysis. This analysis suggests the model is significantly worsened by not specifying a relationship between sensory-motor constructs and cognitive constructs. These findings tentatively support the Dean-Woodcock model of including a Gtk factor with other broad abilities.

CHAPTER IV

General Discussion

The major research questions addressed by this study were:

(1) What factor model best describes the underlying neuropsychological constructs of the Sensory-Motor Battery?

(2) What is the relationship between the neuropsychological constructs measured by the Sensory-Motor Battery and CHC constructs of cognitive abilities as measured by the Woodcock-Johnson Revised Tests of Cognitive Ability?

A factor and confirmatory factor analysis was used to address the first question. Results from the first study suggest the SMB has at least 12 interpretable factors and most parsimoniously consists of at least 4 factors and at most 7 factors. Additionally, the results from the first study demonstrated shared variance between constructs of sensory and constructs of motor functioning. There was evidence of at least one higher-order factor that consisted of both sensory and motor tests (see Table 6 & Table 7). Confirmatory models aided by both theory and empirical evidence suggest a model with 12 specified factors for each group of tests and one higher-order factor provide the best fit of the data for the models compared in this study.

The significant relationship between confirms sensory and motor processes are related, as suggested by much of neurological evidence (Kolb & Whishaw, 1993). This study would also suggest the psychometric measurement of sensory and motor functioning reflects the anatomical functioning of these two constructs in that sensory and motor constructs are highly related. Future research will be needed to more precisely define the relationship among narrow sensory and narrow motor abilities.

The second question addressed in this study involved an examination of the broad factors of the SMB and the factors of the CHC theory. Results from this analysis suggested a significant relationship between the broad factor of the SMB and the third stratum factor of CHC theory. Additional significance testing suggested not specifying a relationship between cognitive abilities and sensory-motor constructs significantly worsened the model. The null hypothesis of cognitive and sensory-motor constructs not be related should be rejected based on these analyses.

Clarification of causal mechanisms behind the relationship of sensory-motor and cognitive constructs can only tentatively be made from this research. A significant problem with this study is no apriori hypotheses were available at the beginning. As such, it was difficult to test specific hypotheses about specific relationships of sensory, motor, and cognitive constructs. The hypotheses addressed in this study were broad but specific enough to determine sensory-motor constructs can viably be included in the CHC model, as proposed by Dean and Woodcock (1999).

CHAPTER V

Summary and Conclusions

Although few apriori hypotheses were available to explain the fairly large correlation between the higher-order SMB factor and the CHC *"g"* factor, several post hoc arguments could be made that would need to be investigated by further research. Although the primary focus of these analyses was on the SMB, examining the results through the perspective of "g" oriented research may be valuable and applicable to this study. "g" oriented research can be succinctly summarized as postulating a single underlying cognitive mechanism at the base of all cognitive activity. Galton (1884) believed intelligence was believed to be a result of sensory acuity. As such, intelligence was measured by tests that measured simple sensory and perceptual acuity. In fact, one measure was a test that measured the strength of grip, which is also in the SMB. Although these theories provided a rationale for the correlation between different types of cognitive abilities, more sophisticated models of cognition rendered them obsolete. It may be the tests on the SMB have some *"g"* loaded tasks. Jensen (1998) states: "At the level of psychometrics, ideally, "g" may be thought of as a distillate of the common source of individual differences in all mental tests, completely stripped of their distinctive features of information content, skill, strategy, and the like, In this sense, *"g"* can be roughly likened to a computer's central processing unit" (p. 74). Additionally Jensen notes that the most *g* loaded tasks involve inductive or deductive reasoning. This is similar to Spearman's view that *"g"* was the eduction of relations and correlates (Spearman, 1927). It is possible that some of the measures in the SMB require inductive and deductive reasoning but do so through a sensory or motor modality. For instance, the highest loading on the first extracted factor (which is often ascribed the "*g*" factor) was Palm Writing Numbers. This task involves writing a number on the palm of the blindfolded subjects hand and asking the subject to guess the number. Since information from the skin is transmitted to the cortex at a much lower fidelity than visual or auditory information, there may be a substantial amount of cognitive inferences to perform these tasks. Similarly, cross and clock construction (which also had a high loading on the first extracted factor) may involve similar processes of deduction. Future research may investigate the degree in which logical inferences are used in performing these sensory and motor tasks. Tests that involve more logical inferences may have a higher loading on "g" than other low inferential tests. Many of these questions could be addressed by using the models in Study 2. To test the hypothesis that some SMB factors may be more or less related to "*g*", the higher-order factor of the SMB (in Study 2) could be eliminated and correlations could be specified between each of the SMB factors and the "*g*" factor. This may also lead to another method to categorize the SMB tests. SMB tests could be categorized based upon their "*g*" loadings. Once categorized, new confirmatory models could be tested and compared to the models tested in Study 1.

Another possibility that might explain the "*g*" relation with sensory and motor functioning is deficits in sensory acuity may influence performance on intelligence but not in a causal manner. Deficits in sensory acuity may distort or limit the amount of information that is available for cognitive processing. If information is initially distorted by the senses, the cognitive mechanisms will more often derive an incorrect solution in answering questions on cognitive tests that involve the sensory modality (e.g. vision, hearing, etc). Although Gf, Gv, and Gs are proposed to reflect different underlying processes, they both heavily rely on visual processing. Deficits in simple visual processing may lead to deficits in cognitive measures that involve vision (e.g., Gf, Gv, and Gs). This hypothesis could also be tested with the models in this study. For example, the higher-order variable of the SMB in Study 2 could correlated with specific CHC factors that involve similar modalities. The cognitive measures of the CHC model could be categorized by the dominate sensory modality (vision or auditory). Correlations between the CHC broad abilities and the sensory tests of the SMB could be estimated. It would be predicted that vision tests of the SMB are correlated with vision tests of the CHC model but not with auditory tests of the CHC model (e.g. Ga & Gc).

This study, at least, suggests the relationship between sensory/motor variables and cognitive ability is complex. Additionally, methodological procedures used to address these questions add to the complexity. In relating the findings of this study to the Dean-Woodcock Neuropsychological Model (Figure 2), representing the sensory and motor tests of the SMB with a single tactile/kinesthetic factor, as suggested by Carroll (1993) is valid only to the extent the factor is seen as a higher order factor that is similar to third-stratum of the CHC model. Since the DW Neuropsychological Model is a model of the broad abilities rather than of "g," a more valid model may incorporate the numerous sensory and motor broad factors contained in the SMB described in this study.

There are several limitations to this study. The first is the differing scales of the SMB and the distribution properties of the sample. Some measures of the SMB may range from 0 to 1 and other tests may range from 0 to 18. It is difficult to determine the extent the different scales of the tests have on the results. Similarly, some tests had more indicators than other tests. Factor analysis will tend to give more weight to a particular factor solely due to the number of indicators of the factor rather than any substantial reason. Future analyses may benefit by replicating the factor analysis in this study but combine similar tests into a composite measures to reduce the number of indicators for any one factor. Another limitation to this study is the sample distributions for the SMB measures. Although scores for these measures were converted into z-scores, this transformation will not change the distribution of the data. Since many of the SMB tests are successfully completed by about 90% of normal individuals, the data distributions for these measures can be highly skewed. Normality of data is an underlying assumption for several of the data analysis techniques used in this study. Although maximum likelihood estimation was used for the model estimation and is fairly robust for distributions, the degree to which the skewness of the data influenced the results is unknown.

It is still difficult to determine exactly where the SMB tests fit in with the CHC constructs. The tests of the SMB have utility in neuropsychological assessment due to their empirically demonstrated ability in predicting brain damage. Due to the historical focus of using these tests as predictors of brain damage, a sound theoretical basis for why these tests predict brain damage has remained obscure. In comparing the tests of the SMB with cognitive tests of the WJ TCA, it is noticed the SMB tests are simpler, require less sophistication, are successfully completed by the majority of the population (thus, have smaller variance), and are narrower in focus (as demonstrated by the factor analysis) than the cognitive tests of the Woodcock-Johnson. Yet, it is known tests that involve complex reasoning (e.g. Gf tests and Category Test) are the most sensitive to the effects of brain damage (Halstead, 1947) but less accurate in predicting localization. The more simple tests that predominate the SMB, however, are more accurate in predicting area of localization. Perhaps a relationship exists between the simplicity and complexity of cognitive function, the degree to which a test is sensitive to brain damage versus accurate in localizing brain damage, and the tests designated place on the CHC hierarchy. Tests that are better measures of more global abilities (Stratum III and Stratum II) are more sensitive to the effects of brain damage and the first to become compromised upon loss of neural system integrity and tests that are more specific in function (Stratum I) are more localized brain functions, that upon being compromised, are fairly accurate in predicting specific areas of brain damage. In this case, the CHC theory holds more promise for assessment than just a taxonomy of cognitive abilities. Clinicians could devise strategies for testing higher order abilities or specific abilities depending upon the referral question and the degree to which the assessment is exploratory (which would examine more global abilities) or confirmatory (which would examine specific areas for deficits). The CHC theory would provide both a taxonomy of abilities and tests at a certain ability level as well a specific reference for the nature of an ability and the abilities nervous system equivalent. A more concrete and statistical method for stating this relationship is a tests "*g*"-loading is a predictor of the degree to which the test is sensitive to overall brain damage versus the tests accuracy in predicting localization of brain damage. Tests with high g-loadings are more sensitive in detecting brain damage but less accurate in predicting its localization. Tests with low "g"oadings (given a rational neuropsychological basis) are less sensitive in detecting the overall effects of brain damage and more accurate at predicting localization of damage. As such, the CHC model may prove to be a good model for determining the degree to which certain abilities are locally or globally distributed in the brain. Tests with higher g-loadings may be more diffusely distributed throughout the brain and cerebral cortex (hence their inability in predicting localization) and neuropsychological tests with lower g-loadings may be less distributed throughout the brain and cerebral cortex. Although these hypotheses are speculative and in need of further research, they will certainly need to be research if the validity and utility of the CHC theory in neuropsychological assessment is to be taken seriously.

In a broader context, the current study is an initial investigation for finding a unified model that incorporates neuropsychological and psychometric constructs. As described by Wright (1999):

> In the history of science there are vast differences between gerrymandering models to give best local descriptions of transient data and searching, instead, for better data that brings inferentially stable meaning to parameter estimates. It is the search for better data that begets discovery. The only way discovery can emerge is as an unexpected discrepancy from an otherwise stable frame of reference. (p. 99).

The success of the present study may be determined by the extent to which it establishes a baseline for comparing and exploring other models that include both neuropsychological and psychometric constructs.

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Table 1

Variable Numeric Label and Description

Subtest Description	Test
Sensory	
1. Lateral Preference	Handedness
2. Near Point Visual Acuity Right	Visual
3. Near Point Visual Acuity Left	Visual
4. Visual Confrontation Right	Visual
5. Visual Confrontation Left	Visual
6. Visual Confrontation Both	Visual
7. Naming Pictures of Objects	Verbal
8. Auditory Perception Right	Auditory
9. Auditory Perception Left	Auditory
10. Auditory Perception Both	Auditory
11. Tactile Examination	Tactile
12. Palm Writing Right	Tactile
13. Palm Writing Left	Tactile
14. Object Identification Right	Tactile
15. Object Identification Left	Tactile
16. Finger Identification Right	Tactile
17. Finger Identification Left	Tactile
18. Simultaneous Localization Right	Tactile
19. Simultaneous Localization Left	Tactile
20. Simultaneous Localization Both	Tactile
21. Simultaneous Localization Right Hand	Tactile
22. Simultaneous Localization Right Hand	Tactile
23. Simultaneous Localization Right Hand Left Cheek	Tactile
24. Simultaneous Localization Left Hand Right Cheek	Tactile
25. Simultaneous Localization Right Cheek	Tactile
26. Simultaneous Localization Left Cheek	Tactile
27. Simultaneous Localization Right Hand Right Cheek	Tactile
28. Simultaneous Localization Left Hand Left Cheek	Tactile
Motor	
29. Gait Station Walking	Motor
30. Gait Station Heel to Toe	Motor
31. Gait Station Hoppping	Motor
32. Gait Station Stationary	Motor
33. Romberg Test Feet Together	Motor
34. Romberg Test One Foot	Motor
35. Coordination Test: Clock	Motor

36. Construction Test: Cross	Motor
37. Mime Movement Right	Motor
38. Mime Movement Left	Motor
39. Left/Right Movement	Motor
40. Finger Tapping Right	Motor
41. Finger Tapping Left	Motor
42. Expressive Speech	Motor
43. Grip Strength Right	Motor
44. Grip Strength Left	Motor`

Table 2
Mean age of sample for Study 1.

Descriptive Statistics					
Age	N	Min	Max	Mean	S.D.
in Years	799	3.00	95.00	32.44	23.78

Table 3
Frequency and Proportion of Sample by Race for Study 1.

Race	f	Percent	Percent	CP
White	667	83.4	83.4	83.4
Black	109	13.6	13.6	97.0
Asian	19	2.4	2.4	99.4
America Indian	3	.4	.4	99.8
Other	2	.3	.3	100.0
Total	800	100.0	100.0	

Table 3
Frequency and Proportion of Sample by Race for Study 1.

	F	Percent	Percent	C P
Right	705	88.1	88.3	88.3
Left	73	9.1	9.1	97.5
Ambi	20	2.5	2.5	100.0
Total	798	99.8	100.0	

Table 5
Descriptive Statistics

	N	Mean	Std. Deviation
LATPREF	796	36.6784	12.3563
Near Point Right	790	27.3797	34.3807
Near Point Left	790	29.1329	47.5427
VC Right	795	7.8151	.7096
VC Left	795	7.7824	.7606
VC Both	794	3.8212	.5906
VC Ear Right	795	7.8352	.6985
VC Ear Left	795	7.8138	.7465
VC Ear Both	793	3.8676	.5114
VC Below Right	794	7.8451	.6775
VC Below Left	794	7.7972	.7734
VC Below Both	794	3.8451	.5385
VC Total Right	795	23.4767	1.9244
VC Total Left	795	23.3748	2.0954
VC Total Both	795	11.5025	1.5324
Naming Pictures	798	4.7419	.6164
Auditory Perception Right	798	7.5890	1.2409
Auditory Perception Left	798	7.5689	1.3681
Auditory Perception Both	794	3.6045	.9620
PW Letters Right	800	8.8263	.8438
PW Letters Left	800	8.8300	.8701
PW Numbers Right	798	7.6629	2.0362
PW Numbers Left	798	7.7920	2.1539
PW Both Right	799	16.4768	2.6242
PW Both Left	799	16.5820	2.7987
Object Id. Right	800	5.5313	.8558
Object Id. Left	800	5.2700	1.0552
Finger Id. Right	800	9.6438	1.3187
Finger Id. Left	800	9.6275	1.3270
SL Hand Right	800	7.9138	.5354
SL Hand Left	800	7.8862	.6275
SL Hand Both	800	3.9138	.4377
SL Left Hand	798	1.9637	.2294
SL Right Hand	798	1.9774	.1927
SL Right Hand Left Cheek	798	2.8446	.5496
SL Left Hand Right Cheek	798	2.8434	.5683
SL Left Cheek	798	1.9737	.2018
SL Right Cheek	798	1.9749	.1988
SL Right Hand Right Cheek	798	.9574	.2021
SL Left Hand Left Cheek	798	.9524	.2131
GS Free Walking	800	3.9312	.4234
GS Heel Toe	799	3.7772	.6645
GS Hopping	799	3.7835	.7928
GS Standing	799	3.9186	.4719
RFT	800	3.8775	.5003
RTH	799	3.3317	.8577
ROF	799	3.0063	.9893
Construction A	798	8.6817	2.1386
Construction B	797	11.5232	3.1437
Coordination Finger Nose Left	786	3.8639	.4435

Coordination Finger Nose R	788	3.8566	.4631
Coordination Hand Thigh	786	14.1940	6.9086
Coordination Hand Thigh	785	14.6788	7.2287
Mime Movement	799	4.6295	.8075
Left Right Movement Right	799	2.8924	.4259
Left Right Movement Left	799	2.9036	.4415
Finger Tapping Right	798	44.0620	10.6433
Finger Tapping Left	798	41.4517	10.3104
Expressive Speech	800	11.6188	4.7989
Strength Grip Right	800	27.3652	14.0374
Strength Grip Left	800	25.3348	13.3164

* VC = Visual Confrontation, PW = Palm Writing, SL = Simultaneous Localization, GS = Gait and Station

Table 6.
Rotated Factor Matrix

	Factor								
	1	2	3	4	5	6	7	8	9
Palm Writing - Numbers/Non-Dominant	0.84								
Palm Writing - Total/Dominant	0.83								
Palm Writing - Numbers/Dominant	0.81								
Palm Writing - Total/Non-Dominant	0.80								
Clock Construction - Part B	0.68								
Object Identification - Right	0.59								
Finger Identification - Left	0.57	0.33							
Finger Identification - Right	0.57	0.38							
Cross Construction - Part A	0.55								
Naming Pictures of Objects	0.53								
Object Identification - Left	0.50								
Left-Right Movement - Left	0.46	0.35		0.33					
Mime Movements	0.43								
Expressive Speech	-0.39								
Left-Right Movement - Right	0.33	0.31		0.31					
Lateral Preference									
Simultaneous Localization - Hand/Both		0.79							
Simultaneous Localization - Hand/Left		0.77							
Simultaneous Localization - Hand/Right		0.71		0.34					
Palm Writing - Letters/Non-Dominant	0.42	0.71		0.40					
Palm Writing - Letters/Dominant	0.47	0.61							
Romberg Testing - Feet Together			0.85						
Gait and Station - Station			0.84						
Gait and Station - Heel-to-toe			0.81						
Gait and Station - Free Walking			0.74						
Gait and Station - Hopping			0.69						
Romberg Testing - One Foot			0.55						
SimLocalization - Right Cheek				0.76					
SimLocalization - Right	0.34			0.67					

Hand										
SimLocalization - Left Cheek		0.34		0.61						
SimLocalization - Left Hand		0.38		0.51						
SimLocalization - Left Hand/Right Cheek	0.33	0.32		0.43	0.40					
Construction - Finger-To-Nose/Right					0.75					
Coordination - Finger-To-Nose/Left					0.74					
SimLocalization - Left Hand/Left Cheek					0.60					
SimLocalization - Right Hand/Right Cheek	0.33			0.40	0.50					
SimLocalization - Right Hand/Left Cheek	0.34	0.32		0.32	0.38					
Visual Confrontation - Total/Right						0.88				
Visual Confrontation - Total/Left						0.79				
Visual Confrontation - Total/Both						0.76				
Auditory Perception - Both							0.91			
Auditory Perception - Left							0.82			
Auditory Perception - Right							0.67			
Strength of Grip - Non-Dominant	0.33							0.86		
Strength of Grip - Dominant	0.35							0.86		
Coordination - Hand-Thigh/Left									-0.91	
Coordination - Hand-Thigh/Right									-0.85	
Finger Tapping - Dominant	0.39									0.[illegible]
Finger Tapping - Non-Dominant	0.41									0.[illegible]
Near Point Visual Acuity - Left										
Near Point Visual Acuity - Right										

*Only loadings of .30 or greater are shown.

Table 7.
Fit Statistics for Factor Solutions 1-12.

Model	x^2	*df*	p	RMSEA	RMSR
One-Factor	25338.21	1175	.000	0.161	0.110
Two-Factor	22419.64	1126	.000	0.154	0.099
Three-Factor	19283.69	1078	.000	0.145	0.080
Four-Factor	17008.97	1031	.000	0.139	0.070
Five-Factor	14999.00	985	.000	0.134	0.061
Six-Factor	13037.61	940	.000	0.127	0.052
Seven-Factor	11507.53	896	.000	0.122	0.050
Eight-Factor	10876.00	853	.000	0.121	0.043
Nine-Factor	8751.13	811	.000	0.111	0.036
Ten-Factor	7538.54	770	.000	0.105	0.033
Eleven-Factor	6527.21	730	.000	0.100	0.010
Twelve-Factor	5894.85	691	.000	0.100	0.026

Table 8.
Results of Confirmatory Factor Analyses for Study 1, Section B.

Model	X2 (df)	p	GFI	NFI	CFI	RMR	AIC
Theory Based							
M1 Two-Factor	20968.13(1081)	<.000	.448	.401	.413	.135	21158
M2 Three-Factor	18559.12(1077)	<.000	.490	.470	.484	.087	18757
M3 Four-Factor	17645.67(1075)	<.000	.520	.496	.511	.277	17847
Empirically Based							
M4 Twelve Factor (uncorrelated)	10741.80(1038)	<.000	.533	.692	.712	.232	10921
M5 Twelve Factor (Mod correlated)	9129.35(1030)	<.000	.624	.738	.760	.210	9325
Theory/Factor Based							
M6 Hierarchical 4 factors	7098.46(1067)	<.000	.681	.797	.822	.074	7316
Hierarchical M7 Mod 4 factors	5973.36(1064)	<.000	.731	.829	.855	.084	6197
M8 Mod 2 factor	5980.85(1069)	<.000	.731	.829	.855	.082	6194
Indep. Model	35012.71(1128)						35108

Figure 1. Horn-Cattell-Carroll model of cognitive ability.

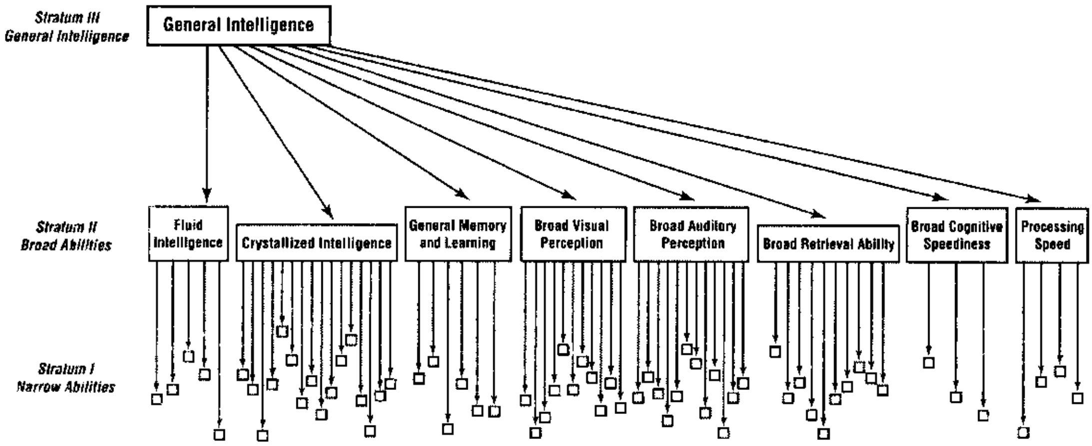


Figure 2. The Dean-Woodcock neuropsychological performance model

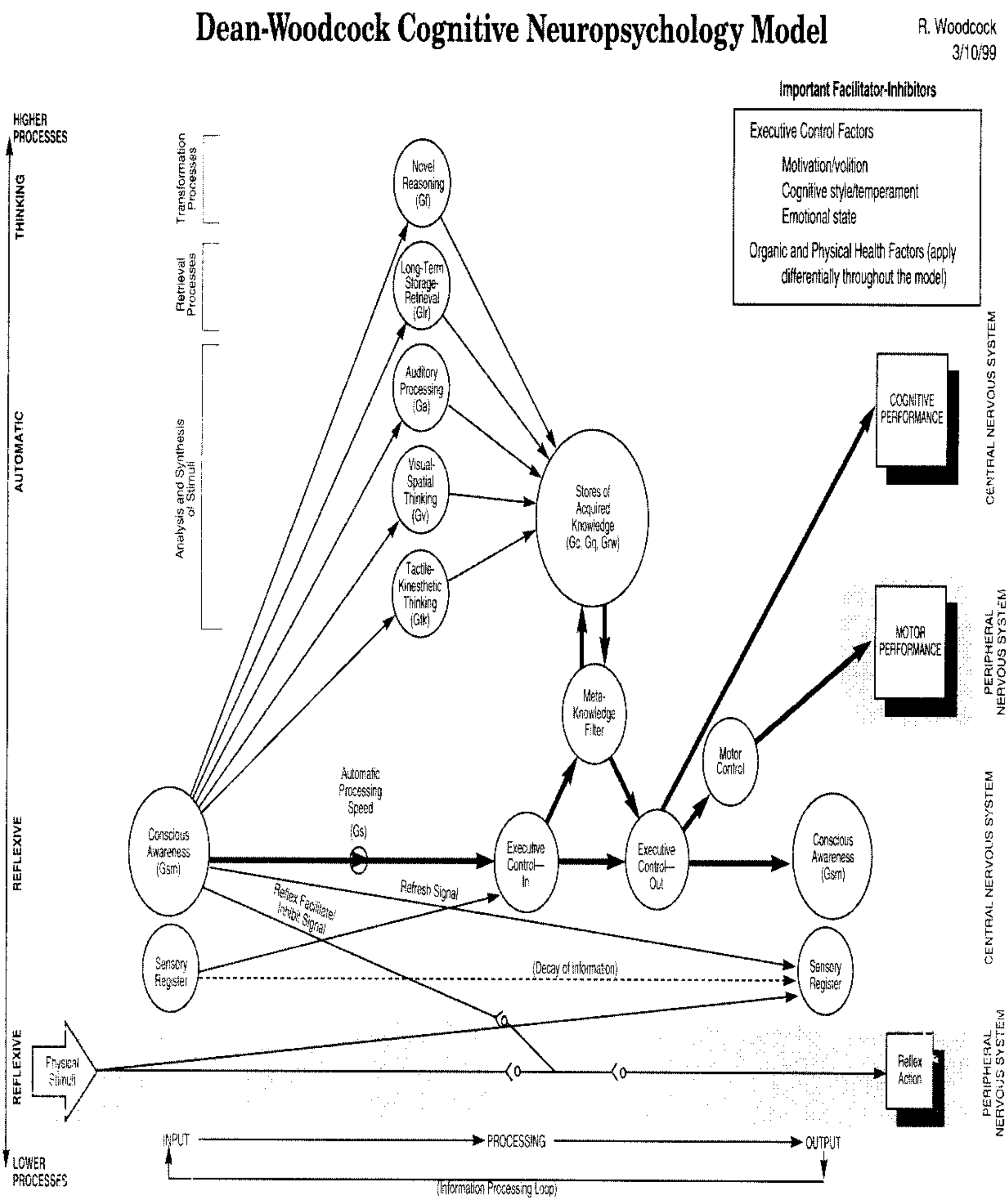


Figure 3. Standardized estimates for the two-factor model of the Sensory-Motor Battery

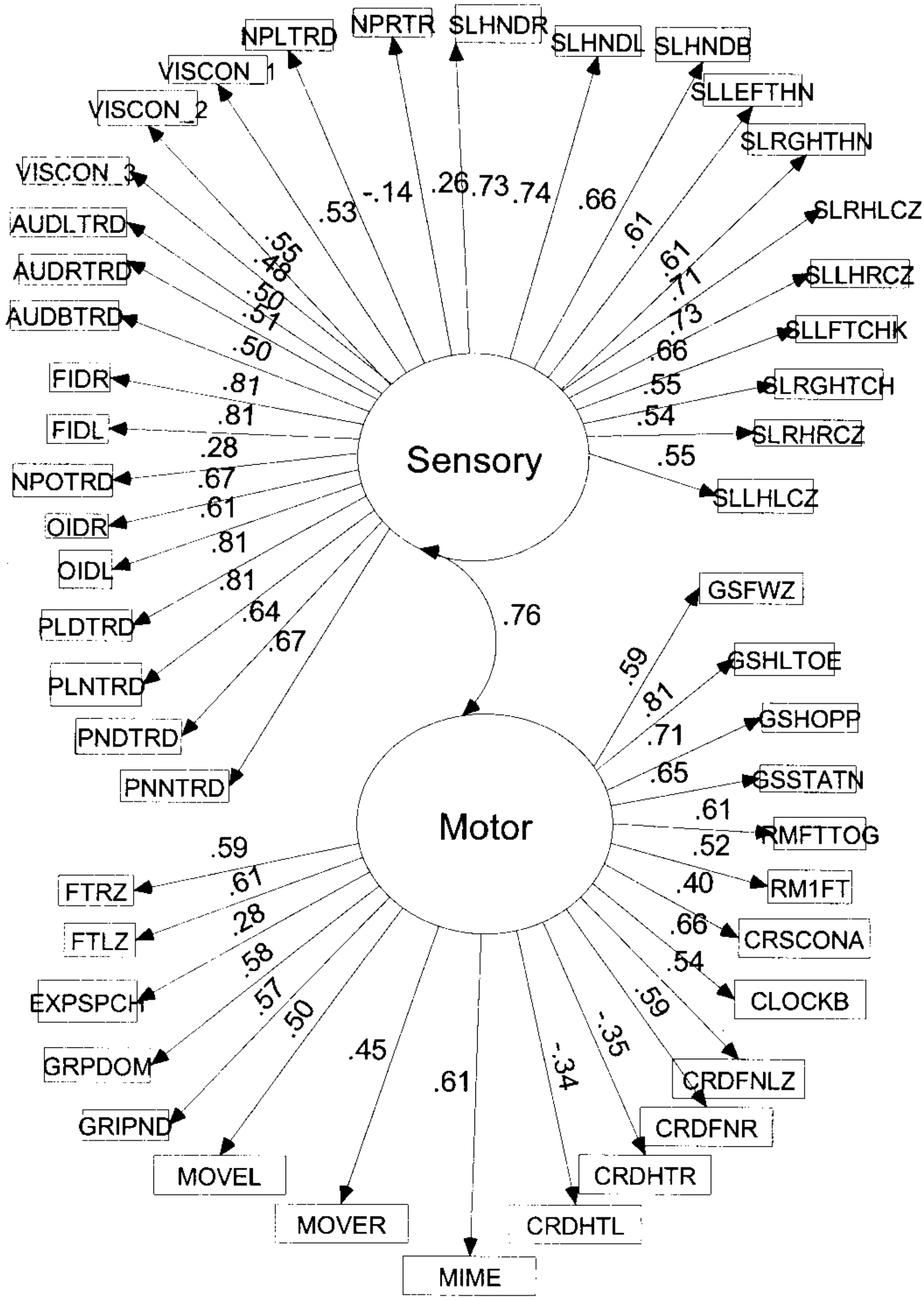


Figure 4. Standardized estimates for the three factor model

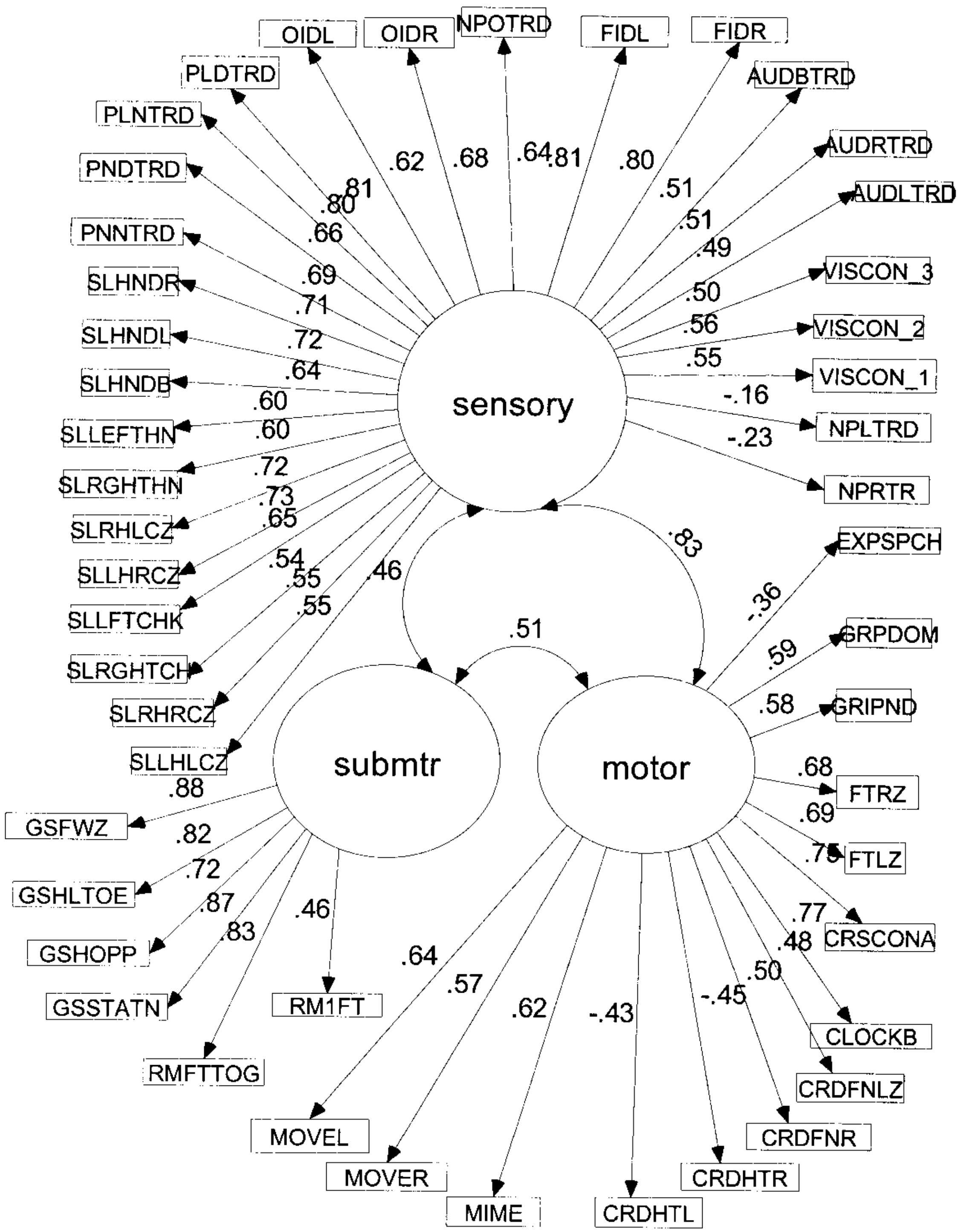


Figure 5. Standardized estimates for the four factor model

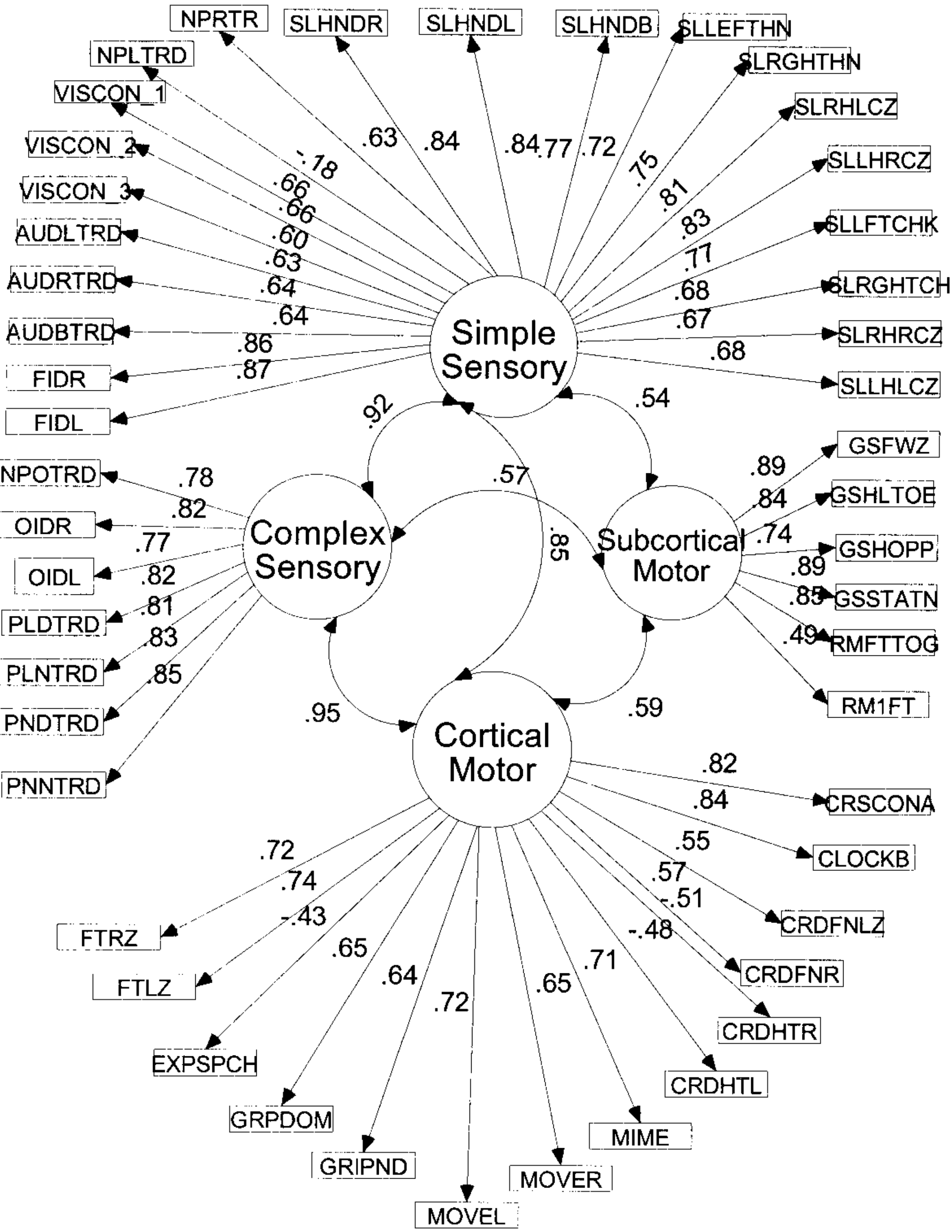


Figure 6. Standardized estimates for the empirical based twelve factor model

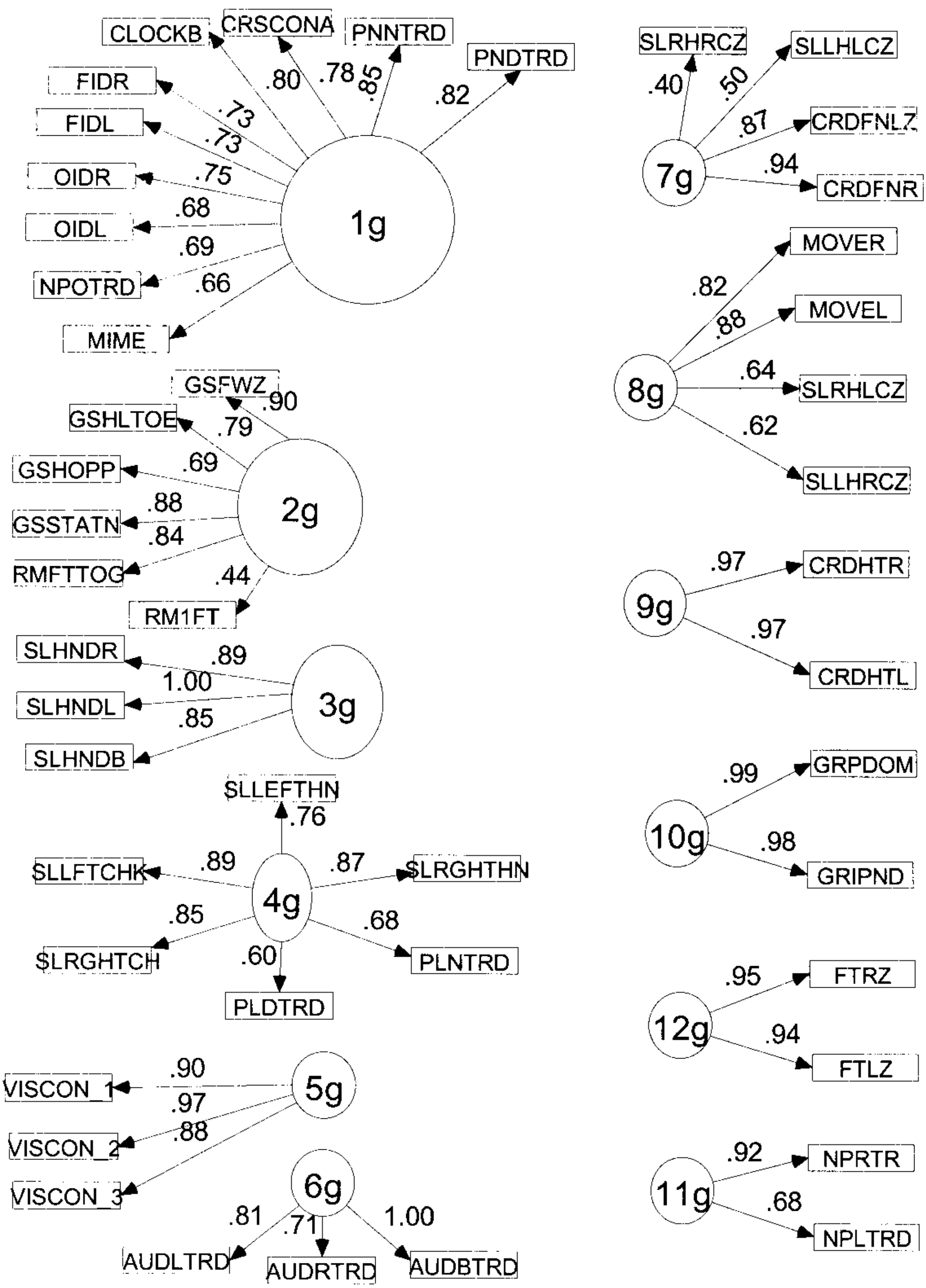


Figure 7 Standardized estimates for the empirical based twelve factor correlated model

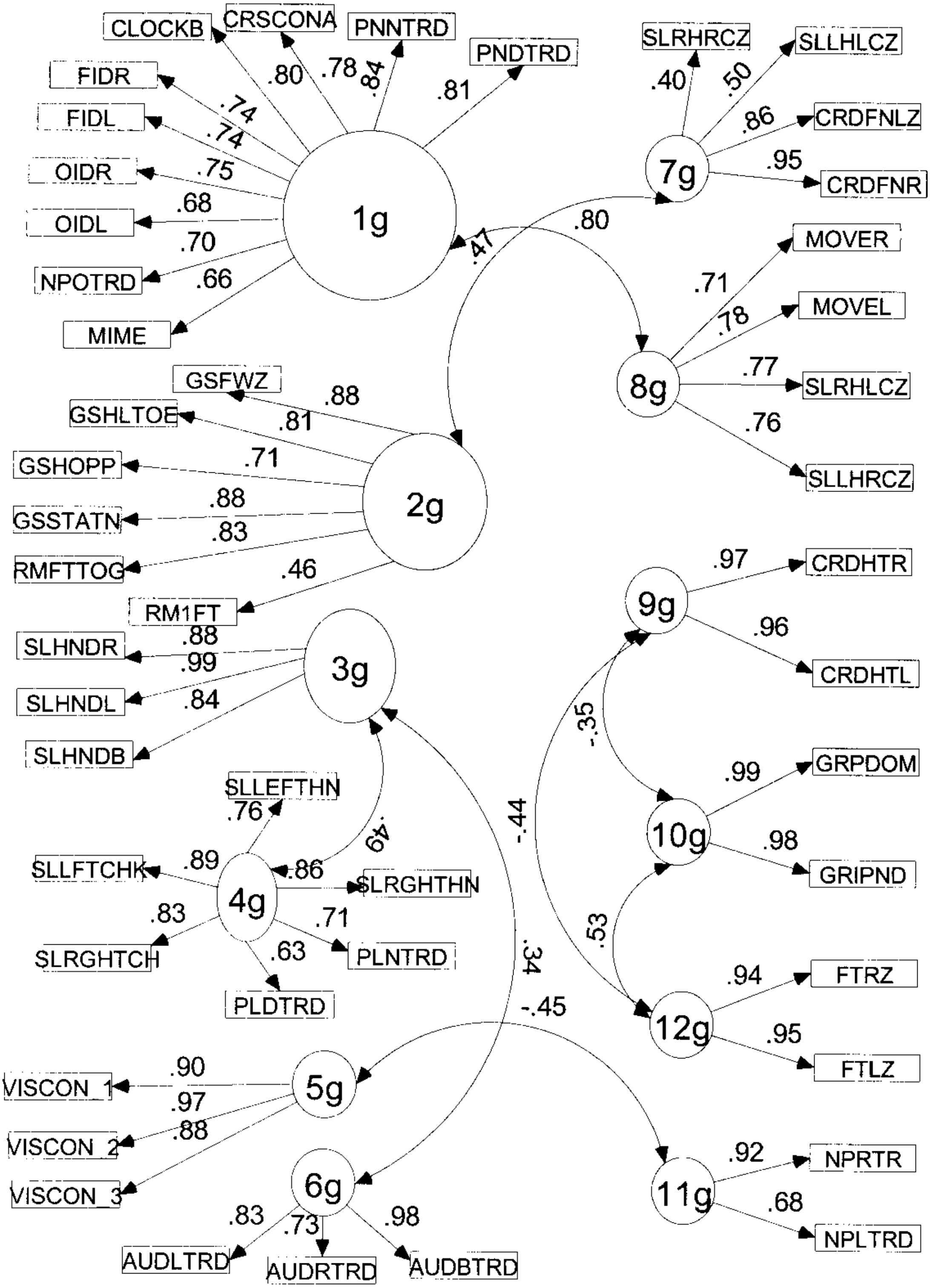


Figure 8. Standardized estimates for the four factor hierarchical model

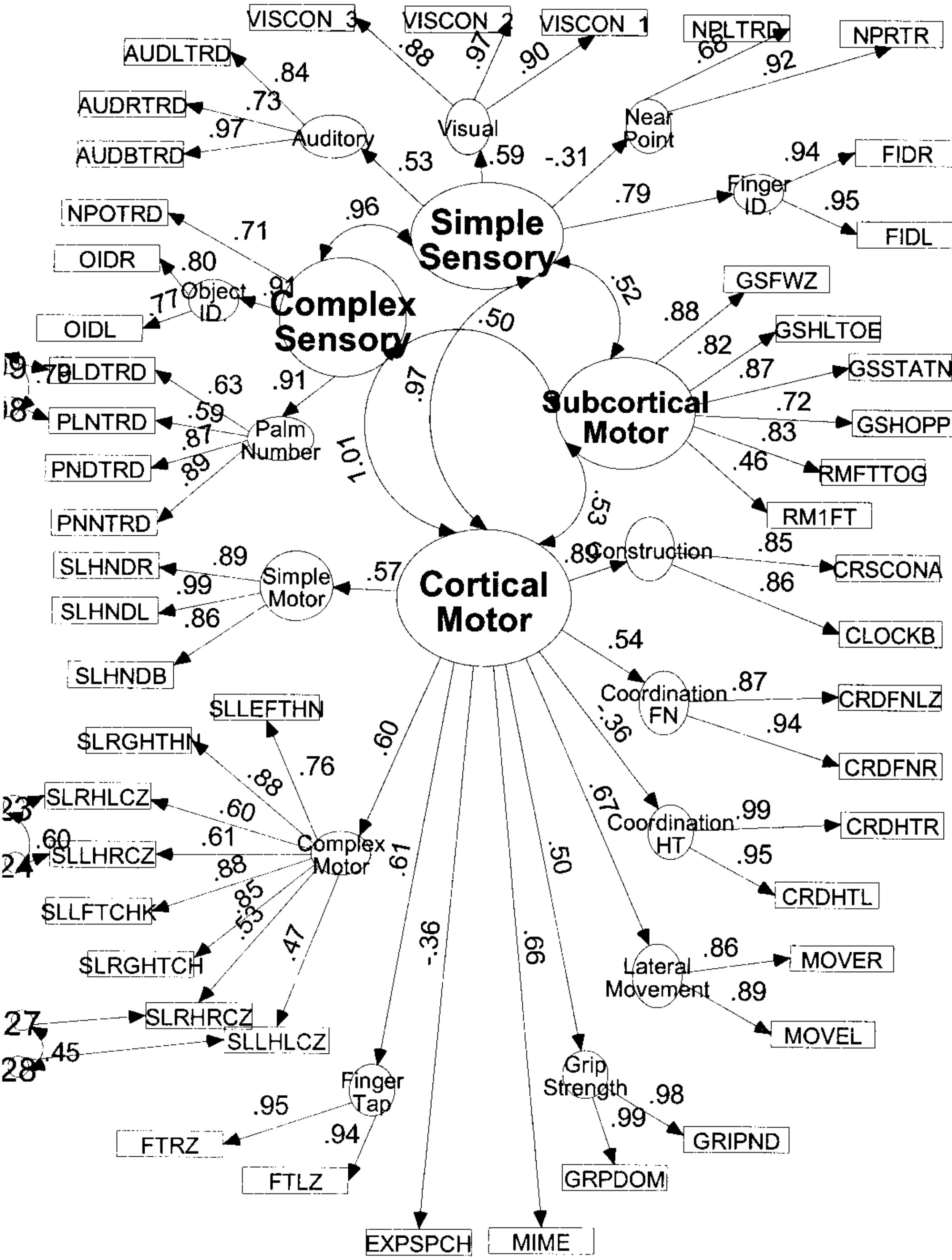


Figure 9. Standardized estimates for the one factor hierarchical model

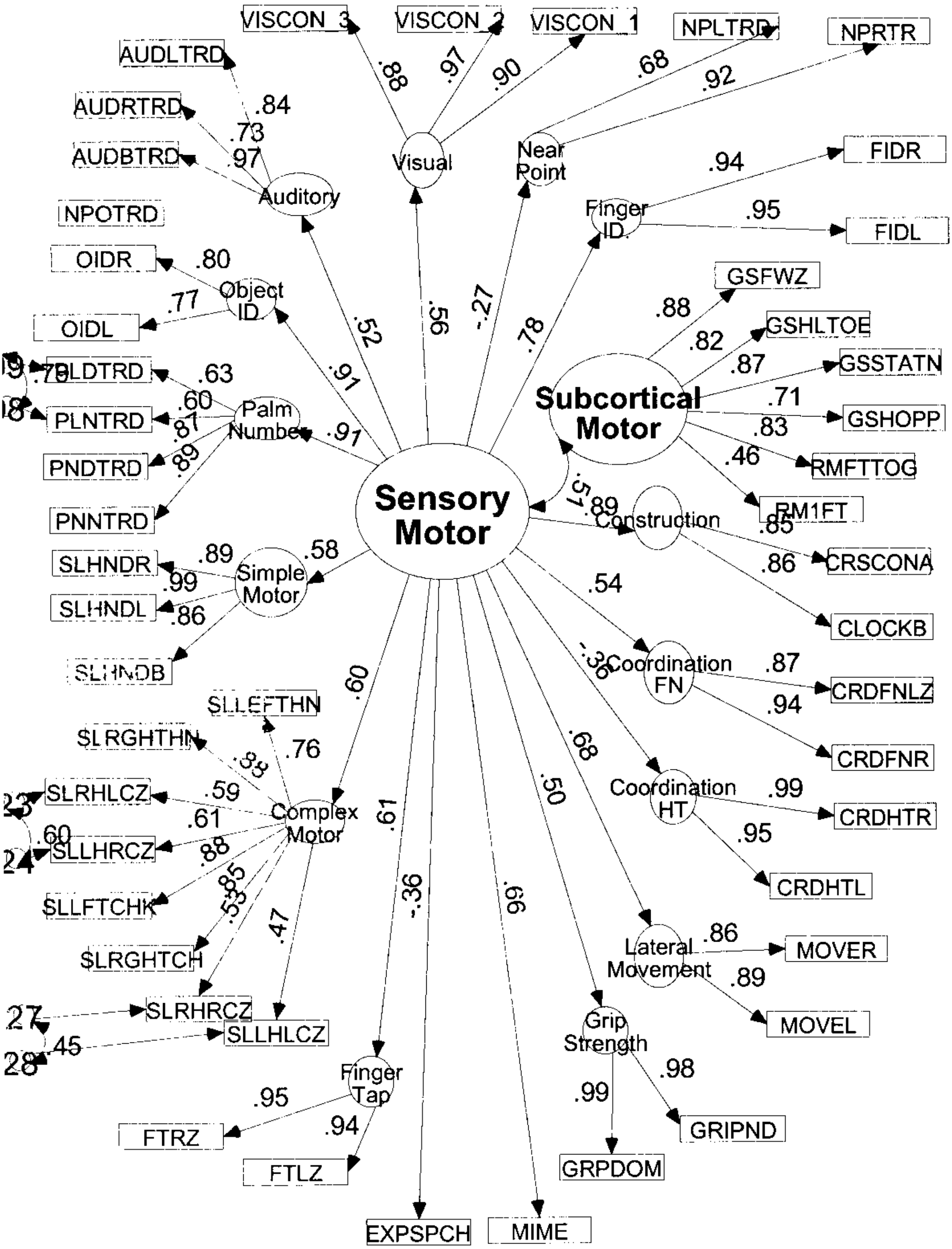
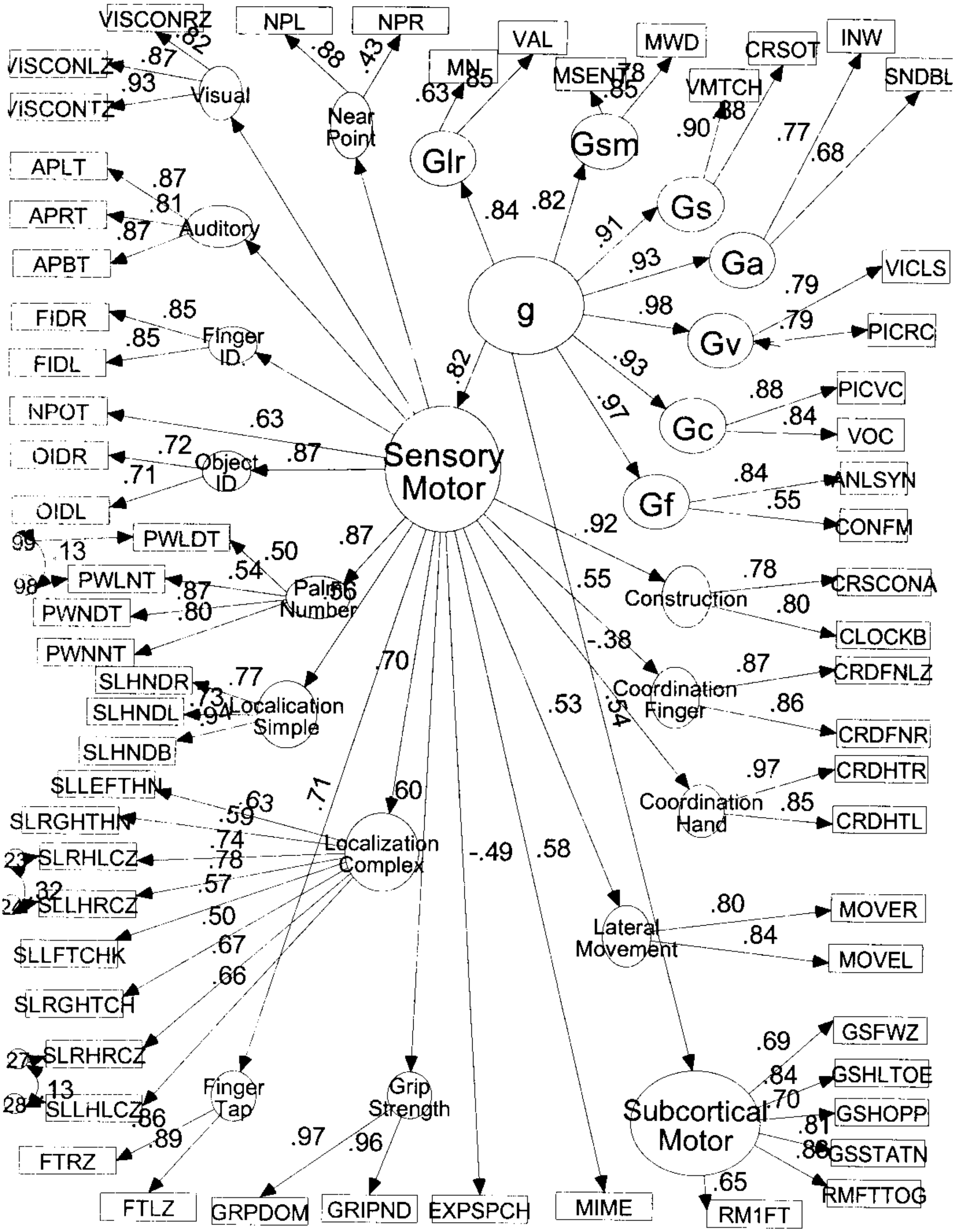


Figure 10. Standardized coefficients for SMB with CHC factors



* estimated coefficient for SMB and “g” = .82.

Appendix 1.

Definitions of Important Terms

Cattell-Horn-Carroll (CHC). A theory of cognitive ability. Initially Gf referred to Fluid Intelligence and Gc referred to Crystallized Intelligence.

Confirmatory Factor Analysis. A statistical procedure used to compare a theoretically based description of a covariance matrix to the empirically derived covariance matrix.

Fit Indices. Indices that indicate how well the researcher's model of the covariance matrix replicates the empirically derived covariance matrix.

Short-term Memory. The ability to hold information in conscious awareness and then use it within a few seconds.

Stores of Acquired Knowledge. Gf-Gc abilities that represent the stores of declarative and procedural knowledge acquired through schooling and other acculturation experiences.

Verbal-Conceptual Knowledge (Gc), called Comprehension-Knowledge in the WJ-III, represents the breadth and depth of knowledge including verbal communication, information, and reasoning when using previously learned procedures.

Thinking Abilities. Composed of four Gf-Gc abilities (Visual-Spatial Thinking (Gv), Auditory Processing (Ga), Long-Term Storage-Retrieval (Glr), and Fluid Reasoning (Gf)). Represents higher level processing of information.

Visual-spatial thinking (Gv) includes spatial orientation and the ability to analyze visual stimuli.

Auditory Processing (Ga) is the ability to analyze and synthesize auditory stimuli.

Long-Term Storage-Retrieval (Glr) is the ability to store information and to retrieve it later through association.

Fluid Reasoning (Gf), is defined as the ability to reason, form concepts, and solve problems that often include unfamiliar situations or procedures.**Processing Speed** (Gs)is the ability to perform automatic or very simple cognitive tasks rapidly.

Correct Decision Speed (CDS) is defined as speediness in finding correct solutions to problems of moderate difficulty.