Rigidity-Flexibility and Cognitive Abilities in Adulthood

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Abstract

The interrelationship of measures of rigidity-flexibility and of psychometric intelligence is examined for the factors of attitudinal flexibility, motor-cognitive flexibility, and psychomotor speed from the Test of Behavioral Rigidity, with the primary mental abilities of Inductive Reasoning, Spatial Orientation, Verbal ability, Numeric ability, Verbal Memory, and Perceptual Speed as measured by the Thurstone Primary Mental Abilities Test and selected measures from the Educational Testing Service Kit of Factor-referenced Tests. The data base for this purpose comes from the fith wave of the Seattle Longitudinal Study, which includes 1628 participants over the age range from 22 to 95 years of age. Cross-lagged relationships between rigidity-flexibility and the mental abilities are also examined for a sample of 837 study participants who were assessed longitudinally seven years apart in both the fourth and fifth cycle of the study.

Rigidity-Flexibility and Cognitive Abilities in Adulthood

Introduction

One of the personality dimensions that has consistently been implicated in the prediction of cognitive decline in old age has been that of rigidity-flexibility (e.g., Schaie, 1958, 1984; Schaie & Parham, 1975). However, it has been recognized that the rigidity-flexibility construct is itself multi-dimensional in nature, and that marker variables used to measure this construct may exhibit differential aging patterns. The question of differential age changes and generational differences in markers of rigdidity-flexibility has been previously examined by Schaie and Willis (1987). In that study increasing rigidity was found for some but not all rigidity-flexibility measures and positive cohort effects favoring the younger participants were also discovered.

This paper examines data from the Seattle Longitudinal Study (SLS) to investigate the interrelationship of measures of rigidity-flexibility and of cognitive abilities. In contrast to our earlier work, we consider rigidity-flexibility at the level of latent constructs describing this domain. We first seek to reconfirm the three dimensionsal factorial structure of the concept (attitudinal flexibility, motor-cognitive flexibility, and psychomotor speed) originally described by Schaie (1955). Next, we examine the possibility that there is overlap between the dimensions of rigidity-flexibility and secondary factor dimensions of the cognitive abilities to which the former construct has been empirically related (Crowne, 1965; Kleinmuntz, 1965). To do so we develop a six-factor cognitive ability measurement model, which expands a previously confirmed five-factor model that includes Inductive Reasoning, Spatial Orientation, Verbal ability, Numeric ability, and Perceptual Speed (Schaie, Willis, Jay, & Chipuer, 1989) by adding markers for a Verbal Memory dimension. We then examine the combined structure of the two domains to examine whether it is plausible to maintain the existence of rigidity-flexibility dimensions that extend beyond the cognitive ability factor space. Given the demonstration of construct validity for the rigidity- flexibility dimensions, we then proceed to examine their stability in a longitudinal sample over a 7-year period, and we report age changes at the latent construct level. Finally, we consider the directionality of influence between rigidity-flexibility and cognitive abilities by examining the system of cross-lagged correlations connecting the two domains.

Related to the longitudinal question to be addressed as well as with regard to the age change findings reported earlier for the individual markers of rigidity-flexibility (Schaie & Willis, 1987) is a major assumption that has received only limited attention thus far, namely whether the factorial structure of assessment instruments remains equivalent both within subjects across time and between groups of subjects of different ages assessed at the same point in time (cf. Schaie & Hertzog, 1985). If satisfactory evidence of factorial invariance were lacking, it would be possible that the validity of quantitative comparisons might be impaired because of the occurrence of qualitative age changes or age differences among groups.

A critical assumption that underlies evaluation of quantitative change across age or differences between different age groups is that the relationship between the ability constructs and measures of these constructs (psychometric tests) in the assessment battery remains invariant across comparisons. That is, quantitative comparisons are meaningful only if there is qualitative invariance (cf. Baltes & Nesselroade, 1973).

The issue of factorial invariance in longitudinal studies of intelligence has thus far been dealt with only for the relation of the first five primary mental abilities to a second-order g factor (Hertzog & Schaie, 1986). This study found highly stable individual differences in the projection of the primaries on the second-order factor over fourteen-year intervals in three samples that had mean ages of 37, 49 and 65, respectively at the inception of these studies. One of the critical questions addressed in this paper, therefore, is whether similar stability can be found as well for the dimensions of rigidity-flexibility.

Characteristics of the Data Base

The Subject Population

Our inquiry into adult cognitive functioning began some 30 years ago by randomly sampling 500 subjects equally distributed by sex and age across the range from 20 to 70 years from the approximately 18,000 members of a health maintenance organization in the Pacific Northwest (Schaie, 1983; Schaie & Hertzog, 1986). The survivors of the original sample were retested and additional panels were added in seven-year intervals. The sampling frame represents a broad distribution of educational and occupational levels, covering the upper 75 per cent of the socio-economic spectrum. The population frame from which we have been sampling repeatedly has grown to a membership of over 300,000 individuals, but the general characteristics remain very comparable.

The primary data to be examined here include the 1628 community- dwelling individuals (743 males and 885 females) who were examined in the fifth SLS cycle during 1983/85 (see Table 1 for a breakdown by age/cohort). These individuals had an average educational level of 14.3 years (*SD* = 3.06; Range: 1 to 20 years); their family income averaged $23,200 (*SD* = $9,606; Range: $1,000 to $50,000+). Occupational levels were rated on a scale from 0 for unskilled to 9 for professional occupations. Those individuals gainfully employed at the time of assessment averaged an occupational level of 6.8 (*SD* = 1.87). Most frequent occupations represented involve skilled trades, clerical, sales, managerial and semi-professional jobs (also see Schaie, 1988b). Of these individuals, 837 (389 males and 448 females) had previously been tested during the 1977 cycle of the study. All participants were in good health when tested; potential participants who were accutely ill or who had sensori-motor problems that would invalidate the use of paper-and-pencil tests were excluded. The longitudinal sub-sample did not differ significantly from the cross-sectional sample in its demographic and descriptive characteristics.

Insert Table 1 about here

The Measurement Variables

Primary Mental Abilities. The original SLS psychometric ability battery was expanded to permit structural analyses that require multiple measures to mark each ability factor. The longitudinal markers included in this battery of necessity (i.e., for consistency across succesive test administrations), employ the test booklet and answer sheet format used since the beginning of the SLS (Thurstone & Thurstone, 1949). All other forms use disposable booklets upon which answers are marked directly (cf. Ekstrom, French, Harman, & Derman, 1976; Schaie, 1985). The cognitive abilities examined in this study broadly sample higher order constructs such as those espoused by Horn (1982, 1986).

Thus fluid intelligence is represented by the abilities of Inductive Reasoning and Spatial Orientation, while Verbal Ability and Numeric Ability stand as representatives of crysttalized intelligence. Verbal Memory and Perceptual Speed are examined as ability samplars for the memory and speed domains, respectively.

Table 2 lists the measures, the primary ability that they mark, their sources, and their test-retest correlations over a two-week interval for a group of 172 subjects. The ability battery is similar to that used in the age-comparative studies of structural invariance by Schaie, Willis, Jay, and Chipuer (1989) except for the addition of a Verbal Memory factor. A brief description of the primary abilities and the measures marking them is given below:

Insert Table 2 about here

Inductive Reasoning. This is the ability to educe novel concepts or relationships.

PMA Reasoning. The subject is shown a series of letters (e.g., a b c c c b a d e f f e) and is asked to identify the next letter in the series.

ADEPT Letter Series. This is a parallel form to the PMA Reasoning test.

Word Series. The subject is shown a series of words (e.g., January, March, May) and is asked to identify the next word in the series. Positional patterns used in this test are identical to the PMA Reasoning test.

Number Series. The subject is shown a series of numbers (e.g., 6, 11, 15, 18, 20) and is asked to identify the next number that would continue the series.

Spatial Orientation. The ability to visualize and mentally manipulate spatial configurations, to maintain orientation with respect to spatial objects, and to perceive relationships among objects in space.

PMA Space. The study participant is shown an abstract figure and is asked to identify which of six other drawings represents the model in two-dimensional space.

Object Rotation. The subject is shown a line drawing of a meaningful object (e.g., an umbrella) and is asked to identify which of six other drawings represent the model rotated in two-dimensional space

Alphanumeric Rotation. The subject is shown a letter or number and is asked to identify which six other drawings represent the model rotated in two-dimensional space.

Test stimuli in the Object and Alphanumeric Rotation tests have the same angle of rotation as the abstract figures in the PMA Space test.

Cube Comparisons. In each item, two drawings of a cube are presented; the subject is asked to indicate whether the two drawings are of the same cube, rotated in three-dimensional space.

Verbal ability. Language knowledge and comprehension is measured by assessing the scope of a person´s recognition vocabulary.

PMA Verbal Meaning. A four-choice synonym test.

ETS Vocabulary. A five-choice synonym test.

ETS Advanced Vocabulary. A five-choice synonym test consisting mainly of difficult items.

Numeric Ability. The ability to understand numerical relationships and compute simple arithmetic functions.

PMA Number. The subject checks whether additions of simple sums shown are correct or incorrect.

Addition. This is a test of speed and accuracy in adding three single or two-digit numbers.

Subtraction and Multiplication. This is a test of speed and accuracy with alternate rows of simple subtraction and multiplication problems.

Verbal memory. The ability to encode, store and recall meaningful language units.

Immediate Recall. Subjects study a list of 20 words for 3 1/2 minutes. They are then given an equal period of time to recall the words in any order.

Delayed Recall. Subjects are asked to recall the same list of words as in Immediate Recall after an hour of intervening activities (other psychometric tests).

PMA Word Fluency. The subject freely recalls as many words as possible according to a lexical rule within a five minute period.

Perceptual speed. The ability to find figures, make comparisons and carry out other simple tasks involving visual perception, with speed and accuracy.

Identical Pictures. The subject identifies which of five numbered shapes or pictures in a row are identical to the model at the left of the row.

Finding A's. In each column of 40 words, the subject must identify the five words containing the letter "a".

Number Comparison. The subject inspects pairs of multi-digit numbers and indicates whether the two numbers in each pair are the same or different.

Rigidity-Flexibility. The multiple dimensions of this construct are measured by the Test of Behavioral Rigidity (TBR; Schaie & Parham, 1975). The TBR was developed as part of an inquiry concerned with determaining the dimensions of the personality/cognitive style trait of rigidity (Schaie, 1955). The test was designed to measure the three dimensions of psychomotor speed, motor-cognitive flexibility, and attitudinal flexibility. In this test seven scores are obtained from the following three tests.

The Capitals Test. Adapted from Bernstein's (1924) study of quickness and intelligence, this test represent the Spearmanian, or "functional" approach to perseveration or rigidity. Subjects spend 2 1/2 minutes copying a printed paragraph that contains some words starting with capital letters, others spelled entirely in capitals, and some starting with lower case letter and their remainder in capitals. Subjects must copy the paragraph in writing, not printing. In the second half of the test, subjects copy the paragraph again, substituting capital for lower case letters, and lower case letters for capitals. A psychomotor speed score is the number of words correctly copied in the first series (copying speed, Cap). A motor-cognitive flexibility score (instructional set flexibility, Cap-R) results from taking the ratio of the number of words correctly copied in the second series to that of the first.

The Opposites Test. A newly constructed test following the work of Scheier and Ferguson (1952). Subjects are given 2 minutes each to work on three lists of words (at a third-grade level of difficulty). The first list requires providing the antonym, and the second list the synonym of the stimulus word. The third list contains selected stimulus words from the previous lists which must be responded to by an antonym if the stimulus word is printed in lower case letters, but by a synonym if printed in capitals. The psychomotor speed score is the sum of correct responses in the first two lists (associative speed, Opp). There are two motor-cognitive flexibility scores. List 3 is examined for responses that are incorrect, responses started incorrectly, or erasures. The first motor-cognitive flexibility score (associative flexibility 1, Opp-R1) is obtained by the formula:

$$100 - \frac{\text{Series 3 errors}}{\text{Series 3 total}} \times 100$$

The second score (associative flexibility 2, Opp-R2) involves the formula:

$$\frac{\text{Series 3 correct}}{1/2\ (\text{Series 1 correct} + \text{Series 2 correct})} \times 100$$

The TBR Questionnaire. This is a 75-item true-false questionnaire that contains 22 rigidity-flexibility items (attitudinal flexibility, R-scale) and 44 masking social responsibility items from the California Psychological Inventory (Gough, 1957; Gough, McCloskey, & Meehl, 1952; Schaie, 1959). It also contains 9 items (behavioral flexibility, P-scale) obtained from the Guttman-scaling of a 17-item perseveration scale first used by Lankes (1915), items being selected to be suitable for all adult ages.

The Assessment Procedure

The measures described above were administered to small groups of subjects as part of a broader 5-hour battery spread over two sessions. The tests are administered in a standard format and order by an examiner assisted by a proctor. Testing locations are at familiar sites close to the homes of our participants. Subjects first were tested in 1956 and survivors were retested in 1963, 1970, 1977 and 1983/85. The data discussed here, however, are restricted to those obtained in 1977 and in 1983/85.

Statistical Procedures

In this paper, we apply restricted (confirmatory) factor analysis to confirm measurement models for the rigidity-flexibility and the cognitive ability domains, to test the overlap of the combined covariance matrices and to assess the hypothesis of factorial invariance of the rigidity-flexibility dimensions across a seven-year interval.

Covariance structure models were formulated using LISREL VI (Jöreskog & Sörbom, 1984) to confirm factor structures and evaluate their equivalence over time (see Jöreskog, 1971; Jöreskog & Sörbom, 1977; Schaie & Hertzog, 1985, for further discussion of the technique). The analysis reported in this paper used only the Y-side parameters in LISREL. The measurement model was specified as

$$y = \Lambda \eta + \varepsilon \quad (1)$$

which in matrix form yields a vector of the order p of the observed y variables, as a function of their regression on m latent variables (factors) in η (eta), with regression residuals ε (epsilon). The $p \times m$ matrix Λ (lambda) contains the regression coefficients (factor loadings). The covariance matrix of the observed variables in the population, Σ (sigma), may then be expressed as

$$\Sigma = \Lambda \Phi \Lambda' + \Theta \qquad (2)$$

where Λ (lambda) is as mentioned before, Φ (phi) is the covariance matrix of the η_{ς} (etas), and Θ (theta) is the covariance matrix of the ε_{ς} (epsilons). Equation (2) represents a restricted factor analysis model that can be generalized to multiple groups (Jöreskog & Sörbom, 1984).

All parameters in our analyses were estimated by the maximum likelihood method as it has known statistical distribution and can be used to make statistical inferences from sample data. Evaluation of the models was based on both criteria - overall fit of the covariances obtained by the hypothesized theoretical structure in the model to the observed covariances in the data, as well as values and statistical significance of individual parameters.

Overidentified models place restrictions on the hypothesized form of Σ (sigma), which can be used to test the goodness-of-fit of the model to the data using the likelihood Chi-Square test statistic. In the exploratory model building stages, diagnostic fit indices such as LISREL modification indices, fitted residuals, and q-plots of the parameters were examined. Differences in Chi-Square between "nested" models (models that have the same specification, with additional restrictions in one model) were used to test the null hypothesis that the restrictions are true in the population. A more restrictive model (i.e., with more restrictions placed upon the model paremeters), nested within a less restrictive model was accepted over the less restrictive model if the difference in Chi-Square in the two models was not significant.

Conversely if the Chi-Square was significant, the less restrictive model was accepted. In view of our large sample sizes adequate attention was given to the LISREL Goodness-of-Fit Index (GFI). This is a normed index which gives the proportional decrease in lack of fit between two nested models, using the poorest fitting model as a norm for comparison, and is relatively less influenced by sample size and departures from multivariate normality than the Chi-Square statistic (Bentler & Bonnet, 1980; but see Bollen, 1986). This index would be 1.0 if a perfect fit of the model to the data were obtained. Factor models with fits in the .8 to .9 range, as the ones reported here, are generally considered useful approximations to the underlying "true" model even if they do not account for all bivariate covariances in the data, provided alternative specifications have been evaluated and ruled out.

For longitudinal factor analysis, it is particularly important to estimate factor models using covariance metric. Standardization into a correlation metric would obscure invariant factor structures because of group differences in observed variances (Jöreskog, 1971, 1979), and would not allow evaluation of longitudinal changes in factor variances. This covariance metric approach requires estimation of factor variances (rather than the traditional procdure of fixing these to unity), by fixing a single regression on each column of lambda to 1. The latent factors are thus assigned the metric of this marked (fixed) variable. Nevertheless, as standardized factor loadings (etc.) are easier to interpret, we provide parameter estimates that have been rescaled to a quasi-standardized metric, using a SAS PROC MATRIX program for scaling longitudinal factor analysis. This rescaling preserves longitudinal constraints on parameter estimates but returns scaled values for factor loadings that are similar to standardized factor loadings.

The percentage of missing data for our analyses was very low ranging from 0.2 to 8.0 percent across all variables. Since our test batteries were constructed using correlated measures, the iterative regression method in the BMDP statistical software package (1985 version) was used to estimate missing data. To avoid that such estimates might induce artificial stability, particular care was taken to use only the data collected at the same time of measurement for purposes of estimating missing data in the longitudinal sub-sample.

In the longitudinal analyses we essentially ask the question whether the rigidity-flexibility dimensions remain qualitatively invariant across time. The comparative factor analysis literature suggests that the required evidence for factorial invariance would be the demonstration of the equality of unstandardized factor pattern weights (factor loadings; see Hertzog & Schaie, 1986; Meredith, 1964; Schaie & Hertzog, 1985). Horn, McArdle and Mason (1983) have focused attention on the distinction between two levels of invariance in factor loadings (with different implications for age change and age differences research) first introduced by Thurstone (1947; pp. 360-369): *configural invariance* and *metric invariance*.

As discussed by Schaie and Hertzog (1985; see also Hertzog & Schaie, 1986), the critical test of change in the measurement properties of repeated measures data involves the test of invariance over time in the (unstandardized) regressions of variables on factors (i.e., the metric invariance in factor pattern loadings). With respect to changes in factor structure, we test hypotheses at three levels of stringency: (a) *complete metric invariance*, implying that there would be *no* difference across time for the best-fitting model determined from the initial factor analysis on the total cross-sectional sample with respect to the factor loadings (regression coefficients relating tests to ability factors) and factor inter-correlations; (b) *incomplete metric invariance*, implying maintenace of factor pattern across time, but allowing for partial differences in the factor variances, covariances and/or pattern coefficients; and (c) *configural invariance*, requiring maintenance of factor patterns, but allowing for differences in factor loadings and factor inter-correlations.

Configural invariance requires that measures marking factors have their primary loading on the same ability constructs across occasions. If configural invariance is not maintained across time or between different cohort groupings, then it is likely that developmental processes or cohort effects may have produced qualitative changes in ability structure. If this were the case, interpretation of quantitative age changes or age differences would then be ambiguous.

Metric invariance requires not only that markers have their primary loading on the same ability construct, but also that the magnitude of the loadings can be constrained equal across time or between groups. It seems reasonable to hypothesize, even if configural invariance can be confirmed, that developmental processes or differential cohort experiences could cause changes or differences in the magnitude of the factor loadings for the ability measures. That is, it may not be possible to obtain complete metric invariance due to shifts or differences in the magnitude of the factor loadings for Tests A and B, even though the tests mark the same ability factor across time or for different cohorts. Finding a lack of metric invariance would raise problems for the interpretation of quantitative changes or differences in individual tests. Such problems could readily be surmounted, however, where quantitative change can be assessed at the level of _factor scores_ rather than observed scores (cf. Hertzog & Schaie, 1988).

Results

Results of our analyses are reported in four parts: (1) analyses pertaining to the structure of the TBR; (2) the structure of the cognitive abilities battery, (3) the factor structure of the covariance matrix including both the TBR and cognitive batteries, and (4) longitudinal analyses of rigidity-flexibility.

Confirmatory Factor Analyses for the Test of Behavioral Rigidity

The cross-sectional sample was split into two random halves of 814 subjects, one for confirmatory factor analysis with model modification and the second for confirmation of the modified model. The initial model for the TBR was based on the factor structure derived from prior analyses on two independent cross-sectional datasets comprising of 200 and 216 subjects respectively (Schaie, 1955). Three factors were identified in these analyses representing psychomotor speed in responding to familiar stimuli, motor-cognitive flexibility in adapting to change or interference in stimuli (as caused by reversing conditions for appropriate response in the test), and attitudinal flexibility reflected in the subjects´ self-report of tolerance to ambiguity, unpredictability and sudden changes in their daily life (see Figure 1).

Insert Figure 1 about here

Covariances of the seven scores obtained from TBR were analysed and the model was identified by fixing the variances of the factors (diagonal of the psi matrix) to 1.0. The loadings of the seven scores on the three factors and the intercorrelations among the factors were estimated. This model fit the data well (χ^2 [11, N = 814] = 94.13, $p < .001$; GFI =.972, AGFI = .953; and Root Mean Square Residual (RMR) = 9.23) but revealed some remaining stress in the modification indices. Since several of the TBR scores are obtained from the same subtests, it was not unreasonable to expect that their errors would be correlated. Four elements in the error matrix corresponding to these correlations were therefore freed. The revised model showed considerable improvement in fit (χ^2 [7, N = 814] = 9.97, p = .19; GFI=.996, AGFI = .995; RMR = 2.13) and was accepted as the final model.

Confirmatory analyses of this model on the other random half of the sample confirmed the excellent fit (χ^2 [7, N = 814] = 9.15, p = 0.24; GFI = .997, AGFI = .996; RMR = 1.99). The fit of the model for the entire combined sample was, of course, equally acceptable (χ^2 [7, N = 1628] = 14.47, p =.04; GFI=.997, AGFI=.997; and RMR = 1.64). Parameter estimates for this final accepted model are shown in Table 3.

Insert Table 3 about here

Confirmatory Factor Analyses of the Cognitive Battery

The procedure for confirming the measurement model for the augmented cognitive battery was similar to that described above. The covariance matrix was analyzed, setting the metric of factor variances to 1.0. The initial model was based on prior analyses by Schaie, Willis, Hertzog, and Schulenberg (1987) for a sample of 401 participants; and by Schaie, Willis, Jay, and Chipuer (1989), with the addition of a memory factor. The base model hypothesized that the 20 cognitive measures can be represented by 6 oblique factors (see Figure 2). As estimated on the first random half of the sample, this model was found to have an adequate overall fit (χ^2 [154, N = 814] = 832.69, $p < .001$; GFI = .908, AGFI = .875; RMR = 8.588). Diagnostic indices of model strain, however, suggested modifications that were followed minding the theoretical considerations and prior empirically findings on the components of the battery. The final accepted model represents a substantial improvement on the original fit (χ^2 [144, N = 814] = 413.58, $p < .001$; GFI = .952, AGFI = .930; RMR = 3.06). The following modification were made: Errors for the spatial measures, except for Cube Comparison, were allowed to correlate as these tests use identical angles of rotation for their stimulus figures. Similarly, the errors for Number Series and ADEPT Letter Series tests were allowed to correlate because of their similar test format.

Insert Figure 2 about here

The modified model was then confirmed on the second half of the sample with the fit remaining to be acceptable, and continuing to represent a marked improvement on the original model (χ^2 [144, N = 814] = 504.84, $p < .001$; GFI = .940, AGFI = .912; RMR = 3.79). The fit for the entire sample was good (χ^2 [144, N = 1628] = 746.77, $p < .001$; GFI = .955, AGFI = .934; RMR = 3.21); parameter estimates for this model are provided in Table 4. The model was characterized by high and statistically significant loadings of the variables on their associated primary ability factors, relatively high communalities and correspondingly low uniquenesses.

Insert Table 4 about here

Factor Analyses for the Combined Batteries

In order to examine the relationship between the TBR and the Cognitive battery, their common covariance matrix was analysed. Exploratory factor analysis of this matrix revealed that 8 to 10 factors were plausible based on indices such as the proportion of variance explained, the number of eigen values greater than 1.0, examination of the scree plot, as well as the Tucker and Lewis (1973) reliability coefficient.

Our first hypothesized model was one of 9 factors representing the 6 cognitive factors and the 3 flexibility factors that were confirmed in the analyses reported above. This model specifies maintenance of the factor pattern structures obtained for the two batteries individually when the batteries are combined. The metric for the latent factors was again fixed to 1.0 to identify the models. Errors corresponding to the individual analyses were also allowed to be correlated in this model, and the factor intercorrelations were left free to be estimated. The combined model yielded a quite reasonable fit (χ^2 [273, N = 814] = 767.35, *p* < .001; GFI = .935, AGFI = .909; RMR = 4.06). Evaluation of the stress indices on this model suggested that two cross-battery regression coefficients needed to be freed to provide an optimal fit. These were the regression of *OppR1* on the Verbal ability factor, and *Word Fluency* on on the Psychomotor Speed factor, resulting resulting in a significant improvement in fit over the initial model ($\Delta\chi^2$ [2, 814] = 92.89, p < .001). As a consequence of this modification, the loadings of the Word Fluency test were lowered on its other two salient factors (Verbal ability and Perceptual Speed). The final accepted model fit well (χ^2 [273, N = 814] = 693.83, *p* < .001; GFI = .941, AGFI = .918; = 3.42). This model was then confirmed on the other random half of the data (χ^2 [273, N = 814] = 858.13; *p* < .001; GFI = .926, AGFI = .897; RMR = 5.37). Parameters for the accepted model based on the total sample (χ^2 [273, N = 1628] = 1261.24, $p < .001$; GFI = .944, AGFI = .922; RMR = 4.14) are reported in Table 5.

Insert Table 5 about here

Longitudinal Analyses of the Rigidity-flexibility Measures

Structural Analyses. Prior to assessing quantitative change in mean levels or correlational stability over time it is desirable to ascertain whether the change occurs in the observed individuals or whether such changes are artifacts of changes in the meaning of what the assessment instruments are measuring. The issue is whether the construct under study and the measures of those constructs, remain isomorphic at different ages.

This analysis extended the TBR structure confirmed above, to a repeated measures factor model for panel data (Alwin, 1988; Jöreskog, 1979), the model being identified by fixing the highest loadings on each factor to 1.0 in the pattern matrix. This model specificed the 14 x 14 covariance matrix of Time 1 and Time 2 scores, with respect to the same three factor dimensions for both occasions. This results in a total of six factors whose intercorrelations across time were freely estimated, and regression coefficients on the corresponding factors were also free to vary over time. We hypothesized in advance that this model would require, what has been termed as autocorrelated residuals (Sörbom, 1975; Wiley & Wiley, 1970). That is, the reliable variance of the observed variables not accounted by the common factors within time was expected to covary over time. The covariances of the residuals are orthogonal to the common factor covariances over time and are needed to provide unbiased estimates of the stability of individual differences in the factors (see Hertzog & Schaie, 1986; Sörbom, 1975).

This least constrained basic model was found to have a good fit (χ^2 [47, N = 837] = 79.02, p =.002 ; GFI = .987, AGFI = .976; and RMR = 4.60) indicating that configural invariance had been attained. The latter level of invariance which has been termed as "the practical scientist's concept of invariance" implies that the same factors are identified at both occasions on which the observed variables load in the same pattern.

At this point our interest shifted to testing hypotheses regarding more stringent specifications of cross-occasion invariance for the parameter matrices. To evaluate the hypothesis of longitudinal invariance in the factor pattern coefficients, the regression weights were fixed equal across time. This more constrained model fit the data, but the change in Chi-Square ($\Delta\chi^2$ [4, N = 837] = 33.55, p < .001) significantly reduced the model fit and had to be rejected. When confidence intervals (2 SEM) were constructed around the estimated regression weights we noted that only one of the observed variables (<u>Opp-R1</u>) had significantly different loadings on the Motor Cognitive flexibility factor from time 1 to time 2. An alternate model was tested therefore that constrained all corresponding lambdas equal except Opp-R1, and was found not to differ significantly from the base model ($\Delta\chi^2$ [3, N = 837] = 5.57, $p < .10$).

The hypothesis regarding equality of factor variances and covariances over seven years was next tested. Both models, one specifying all factor variances and the other specifying all factor covariances equal over time were evaluated. The global hypotheses of overall invariance of the factor variance-covariance parameters were found untenable when examining resulting changes in Chi-Square. Inspection of 2 SEM confidence intervals for the corresponding parameters in time again revealed the specific significant stresses in this model. The final model that accepted as best fitting the data was one of incomplete metric invariance. The Motor-cognitive Flexibility factor was noted to have a significantly higher loading for Opp-R1, and a significant increase in variance at Time 2. The variance of the Psychomotor Speed factor also increased significantly at Time 2, resulting also in the increase of the covariance between this factor and the Motor-cognitive Flexibility factor. On the other hand, the variance of Attitudinal Flexibility and it´s covariance with the other factors remained invariant across time. The fit for the accepted incomplete metric invariance model remained excellent (χ^2 [53, N = 837] = 89.91, $p = .001$; GFI = .985, AGFI = .970; RMR = 5.094); the path model for the longitudinal factor analysis is shown in Figure 3, and the relevant parameters are shown in Table 6.

Insert Figure 3 and Table 6 about here

The standardized solution revealed that the stability coefficients for the latent variables for psychomotor speed and motor-cognitive were equal to or very close to 1.0, and the stability for attitudinal flelxibility was good. Thus individual differences on the first two flexibility factors were almost perfectly preserved over a seven year retest interval even though the factor variances increased at Time 2.

Cross-lagged Analyses. Our longitudinal data permit the estimation of cross-lagged correlations between factor scores for the three rigidity-flexibility dimensions and the five ability markers from the Primary Mental Abilities test (PMA). in order to examine time-dependent reciprocal relationships between the two domains. Factor scores for the rigidity-flexibility dimensions were calculated from regression weights obtained in the structural model with all but one loadings set equal over time. These loadings (regression weights) were standardized to a correlation metric and orthonormalized to determine the weights assigned to the linear combinations of the variables entering the factor scores. The cross-lags were corrected for changes in reliability and stationarity (Kenny, 1975) and their significance assesed with the Pearson-Filon test.

The direction of significant lagged effects (p < .05), was from flexibility-rigidity to the mental abilities. Thus, 1977 Motor-cognitive Flexibility had lagged effect on 1984 performance on the Verbal Meaning test; Attitudinal Flexibility on Number, and Psychomotor Speed on Word Fluency. The overall IQ in 1984 computed taking the linear combination of the five Abilities (Thurstone & Thurstone, 1949) showed a lagged effect from Attitudinal Flexibility and Psychomotor Speed in 1977.

Changes in Mean Level of Rigidity-Flexibility. In order to assess mean level changes in factor scores over the seven year interval, data were standardized to Time 1 performance and factor scores transformed to T-Scores (X = 50; SD = 10). Subjects were classified into 9 birth-cohorts, and examined by means of a repeated measures 9 (cohorts) x 2 (sex) x 2 (occasions) Analysis of Variance for each of the three rigidity-flexibility factors. For Psychomotor Speed main effects were noted for cohort and gender on both occasions. The multivariate test for the time by cohort effect was significant (F[8, 819] = 3.64, p <.001) indicating differential age changes in cohorts over the seven year span. The MANOVA test for the occasion effects was also significant (F[1, 819] = 9.60, p <.001) indicating positive mean level changes in Psychomotor Speed over time.

Motor-cognitive flexibility showed significant cohort by time effects (F[8,819] = 6.28, p <.001) and as expected main effects for test occasion (F[1, 819] = 46.95, p <.001). On the other hand while cohorts differed on mean levels at each occasion on Attitudinal flexibility (*F*[8,818] = 17.99, *p* < .001), demonstrating between subject effects, no multivariate effects for time of measurement were found to be significant.

Mean differences across seven years were cumulated for successive cohorts in order to show the extent of estimated cumulative age changes. These are graphically represented in Figure 4. As can be seen there is substantial increase in flexibility for the Psychomotor Speed dimension, substantial decrease for the Motor-cognitive Flexibility dimension, but only minimal change for Attitudinal Flexibility.

Insert Figure 4 about here

Discussion and Conclusions

The major purpose of this paper was to examine the structural relationship between rigidity-flexibility and and cognitive abilities in adulthood since rigidity-flexibility has long been implicated as a potent personality factor that might help explain individual differences in cognitive decline from young adulthood into advanced old age. We examined this issues with the help of a large data base including both cross-sectional and longitudinal data obtained from the Seattle Longitudinal Study.

As the first step in this enterprise we reconfirmed the three-dimensional structure of the Test of Behavioral Rigidity that had been originally established in the 1950s with smaller samples and factor-analytic methods that would now be considered obsolete. In the present study we take advantage of LISREL procedures to fit the hypothesized parameters as well as the error structure upon a large sample (N = 1628) that represents the adult age range from the 20s to the 80s. This analysis permits us to accept the original model with an excellent fit, provided we allow for the inter-correlation of the errors for two of the observed variables. As a second step we also reconfirmed the measurement model for a multiply-marked six factor ability battery, which represents our target to determine whether or not the rigidity-flexibility dimensions represent individual difference variance in their own right, or whether these dimensions will vanish when projected into the ability factor space.

Our first test of the plausibility of a rigidity-flexibility domain that is distinct from the ability domain was to determine the extent of the factor space for the joint battery. This analysis led to the conclusion, that more factors were required to account for the joint variable system than were needed for the individual domains. We consequently began to test for the most parsimonious model that would account for a nine factor space including both domains as individually determined. We were able to accept a well-fitting solution that met this criterion quite adequately. The overlap across domains was minimal, with none of the observed variables for either domain collapsing upon the other. However, the ability measure of Word Fluency did split part of its variance upon the Psychomotor Speed factor of the TBR, while one of the associative flexibility scores (Opp-R1) required a significant loading on the Verbal ability factor.

A number of other competing models were also tested for the combined data set. These models included 8 and 10 factor alternatives, models with a common speed factor, a pervasive G factor set orthogonal to other factors, etc. All of these models were evaluated on all of the fit criteria applied to the preferred model but were found either to be fitting less well than the accepted model, or being problematic in terms of estimation procedures. Some of these models could have been competing alternatives when tested on the first random half of the data, but did not fit the other half as well and were consequently rejected.

Since the factor intercorrelations obtained in the 9 factor model were fairly high for at least three pairs of latent variables, nested modelling was used to test whether a more parsimonious model could be obtained by combining factors. Three such nested models were tested: (a) Motor-cognitive flexibility was combined with Inductive Reasoning, (b) Motor-cognitive flexibility was combined with Spatial Orientatione, and (c) Psychomotor Speed was combined with Perceptual Speed. In all three models the change in the Chi-Square for the degrees of freedom gained was significant, indicating that any combination of factors reduced the fit to the data and that the 9 factor model described above was indeed the best fitting model.

Having established the distinct nature of the rigidity-flexibility domain, we next investigated its stability over a seven year interval. We proceeded to do so by testing successive nested models that specified different levels of factorial invariance. A well-fitting base model required only configural invariance; that is, maintenance of the factor pattern across time. This model was contrasted with the most stringent metric invariance model, requiring invariance of all factor loadings and of the factor variances and convariances, which had to be rejected. Being unable to obtain complete metric invariance is not surprising, since on substantive grounds (cf. Horn, McArdle, & Mason, 1983; Reinert, 1970) we would expect minor changes in structure to affect the stability of any factor configuration over time. We were, however, able to demonstrate at least partial metric invariance. The finally accepted most constrained model, which did not differ significantly from the least constrained model, required that we allow the regression of only one observed variable (Opp-R1) to vary upon its latent construct across time. In addition, it was also necessary to acknowledge increases in the factor variances for Motor-cognitive Flexibility and Psychomotor Speed, as well as their covariance over time. However, auto-correlations for two of the factors across time were close to unity, indicating preservation of virtually perfect ordering of individual differences across time on these latent constructs.

The implication of these structural changes is that the factorial composition of the measures of flexibility-rigidity remains stable over time, and thus their mean levels can be validly compared in aging studies except for one of the measures of associative flexibility (cf. Schaie & Willis, 1987). Similarly, mean levels of factor scores are comparable, with the recognition that variation and covariation of two of the construct increases over time. It should be noted, of course, that our analyses cover a sample extending over an extensive age range. More fine-grained analyses of sub-samples with limited age ranges are likely to show some variation in the specific parameters that must be constrained to obtain maximal fit across time for a more age-homogenous sample.

We next examined the lagged relations between the factor scores for flexibility-rigidity and five of the primary mental abilities for which longitudinal data (N = 837) were available to us. Because we had only single measures for each of the abilities we chose to employ cross-lagged correlation methods (Kenney, 1975). While the application of linear structural relations methods would provide a more rigorous test of "causality", particularly in extreme data (Rogosa, 1980, 1988), the lagged relationships observed here do indicate noteworthy trends regarding direction of relationships in well behaved data. As reported earlier (Schaie, 1983) for a smaller sample, all significant lagged relationships were in the direction from rigidity-flexibility at the earlier point in time to abilities at the later point in time. Specifically, these findings suggest a positive relationship over time between certain dimensions of rigidity-flexibility and selected abilities.

We finally examined longitudinal age changes in flexibility-rigidity over the seven year interval for the latent constructs confirmed in this study. To do so we divided our sample into smaller sub-sets. In terms of mean level differnces, we noted significant cohort differences in the direction of greater flexibility for more recently born cohorts for all three of our flexibility factors. Significant gender differences, favoring women, were observed only for Psychomotor Speed. Significant age changes did occur, particularly for the older cohorts, over the seven year interval for Psychomotor Speed and Motor-cognitive Flexibility. The unexpected increment in Psychomotor Speed across age needs to be viewed with caution because of the limited invariance of this dimension shown in the longitudinal factor analyses. Equally interesting, is the lack of significant change in mean levels on Attitudinal flexibility over this time period, reflecting the importance of this dimension as an individual differences variable that seems to be more subject to attitudinal changes across generations than across age.

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Table 1

Age and Sex Distribution of the Cross-sectional Sample

Group	SLS Cohort	Date of Birth	N			Mean Age
			M	F	T	
1	1-2	1886 - 1899	18	23	41	88
2	3	1900 - 1906	63	74	137	81
3	4	1907 - 1913	120	140	260	74
4	5	1914 - 1920	137	154	291	67
5	6	1921 - 1927	127	135	262	60
6	7	1928 - 1934	92	102	194	53
7	8	1935 - 1941	62	92	154	46
8	9	1942 - 1948	53	71	124	39
9	10-11	1949 - 1962	71	94	165	29
Total Sample			743	885	1628	59

Note - Following the convention used in all reports from the SLS, lower cohort numbers represent earlier-born (older) subjects.

Table 2

Psychometric Intelligence Measurement Battery

Primary Ability	Test	Source	Test-Retest Correlation
Inductive Reasoning	PMA Reasoning (1948)	Thurstone & Thurstone, 1949	.884
	ADEPT Letter Series (Form A)	Blieszner et al., 1981	.839
	Word Series	Schaie, 1985	.852
	Number Series	Ekstrom et al., 1976	.833
Spatial Orientation	PMA Space (1948)	Thurstone & Thurstone, 1949	.817
	Object Rotation	Schaie, 1985	.861
	Alphanumeric Rotation	Willis & Schaie, 1983	.820
	Cube Comparisons	Ekstrom, et al., 1976	.951
Numerical Ability	PMA Number (1948)	Thurstone & Thurstone, 1949	.875
	Addition (N-1)	Ekstrom et al., 1976	.937
	Subtraction & Multiplication (N-3)	Ekstrom et al., 1976	.943
Verbal Ability	PMA Verbal Meaning (1948)	Thurstone & Thurstone, 1949	.890
	ETS Vocabulary (V-2)	Ekstrom et al., 1976	.928
	ETS Advanced Vocabulary (V-4)	Ekstrom et al., 1976	.954
Perceptual Speed	Identical Pictures	Ekstrom et al., 1976	.814
	Finding A´s	Ekstrom et al., 1976	.860
	Number Comparison	Ekstrom et al., 1976	.865
Verbal Memory	Immediate Recall	Zelinski et al., 1979	.820
	Delayed Recall	Zelinski et al., 1979	.732
	PMA Word Fluency	Thurstone & Thurstone, 1949	.896

Table 3

Rescaled Solution for the Accepted Riditity-Flexibility

	Factor loadings			
Variables	Psychomotor	Motor-Cognitive	Attitudinal	Unique Variance
Speed	Flexibility	Flexibility		
Opposites	.913			.166
Capitals-NR	.682			.535
Capitals-R		.421		.822
Opposites-R1		.609		.629
Opposites-R2		.606		.633
Rigidity			.734	.462
Perseverance			.515	.735

	Factor Intercorrelations		
Psychomotor Speed	1.000		
Motor-Cognitive Flexibility	.836	1.000	
Attitudinal Flexibility	.545	.620	1.000

Note: χ^2 (7, N = 1628) = 14.47, *p* =.043; GFI=.997, AGFI=.997; RMR=1.64.

Table 4
Rescaled Solution for the Accepted Cognitive Model

Variables	Induct. Reason.	Spatial Orient.	Verbal	Number	Percept. Speed	Verbal Memory	Unique Var.
	Factor Loadings						
PMA Reasoning	.936						.124
ADEPT Letter Series	.896						.199
Word Series	.915						.163
Number Series	.708						.387
PMA Space		.754					.432
Object Rotation		.753					.433
Alphanumeric Rotation		.775					.400
Cube Comparison		.733					.462
PMA Verbal Meaning			.426		.647		.238
ETS Vocabulary			.911				.170
Advanced Vocabulary			.900				.191
PMA Number				.852			.274
Addition				.956			.086
Subtraction & Multiplication				.798	.160		.205
Identical Pictures					.841		.293
Number Comparison					.616		.401
Finding A´s			.132		.510		.683
Word Fluency			.313		.357	.158	.572
Immediate Recall						.950	.098
Delayed Recall						.946	.104

Factor Intercorrelations

Induct. Reasoning					
Spatial Orient.	.859				
Verbal ability	.468	.249			
Numeric ability	.516	.408	.362		
Perceptual Speed	.873	.855	.295	.517	
Verbal Memory	.647	.512	.370	.328	.667

→ Note : $\chi^2(144, N=1628) = 746.77$, $p < .001$; GFI = .955, AGFI = .934 ; RMR =

Table 5

Rescaled Solution for the Combined Rigitity-Flexibility and Cognitive Ability Battery

	Factor loadings									
Variables	I	S	V	N	Ps	M	PS	MCF	AF	Unique Var.
PMA Reasoning	.935									.127
ADEPT Letter Series	.895									.199
Word Series	.916									.160
Number Series	.710			.127						.386
PMA Space		.757								.427
Object Rotation		.759								.424
Alphanumeric Rotation		.775								.399
Cube Comparison		.731								.466
PMA Verbal			.429		.646					.236
Vocabulary II			.913							.167
Vocabulary IV			.898							.194
PMA Number				.851						.275
Addition				.947						.085
Subtraction & Multiplication				.799	.164					.203
Identical Pictures					.851					.276
Number Comp.				.262	.605					.406
Finding A´s			.134		.492					.701

Table 5 (Continued)

Variables	I	S	V	N	Ps	M	PS	MCF	AF	Unique Var.
Word Fluency						.111	.613			.523
Immed. Recall						.950				.097
Delayed Recall						.946				.106
Opposites							.885			.217
Capitals-NR							.714			.490
Capitals-R								.395		.844
Opposites-R1								.500		.617
Opposites-R2								.642		.588
R-Scale									.758	.426
P-Scale									.498	.752

Factor Intercorrelations

Inductive Reasoning	1								
Spatial Orientation	.859	1							
Verbal ability	.469	.249	1						
Numeric ability	.516	.407	.361	1					
Perceptual Speed	.870	.855	.294	.502	1				
Memory	.647	.512	.372	.326	.663	1			
Psychomotor Speed	.845	.709	.594	.599	.862	.653	1		
Motor-Cogn. Flexibility	.911	.916	.395	.441	.868	.630	.835	1	
Attitudinal Flexibility	.546	.456	.420	.234	.530	.456	.550	.580	1

Note: χ^2(273, N=1628) = 1261.24; GFI = .944; AGFI = .9[illegible]; RMR = 4.145

Table 6

Rescaled Solution for the Accepted Longitudinal Riditity-Flexibility Model

Factor loadings

Variables	Psychomotor Speed		Motor-Cognitive Flexibility		Attitudinal Flexibility		Unique Variance	
	1977	1984	1977	1984	1977	1984	1977	1984
Opposites	.933	.933					.154	.108
Capitals-NR	.660	.660					.578	.550
Capitals-R			.393	.393			.851	.850
Opposites-R1			.519	.733			.698	.502
Opposites-R2			.597	.597			.663	.637
Rigidity Scale					.732	.732	.478	.449
Perseverance Scale					.461	.461	.795	.798

Factor Intercorrelations

	PS 77	MCF 77	AF 77	PS 84	MCF 84	AF 84
Psychomotor Speed 1977	1.000					
Motor-Cognit. Flex. 1977	.825	1.000				
Attitudinal Flex. 1977	.548	.647	1.000			
Psychomnotor Speed 1984	.954	.837	.555	1.000		
Motor-Cogn. Flex. 1984	.765	.997	.575	.806	1.000	
Attitudinal Flex. 1984	.535	.607	.796	.490	.565	1.000

χ^2(53, N=837) = 89.41, p = .001; GFI = .985, AGFI = .970; RMR = 5.09

Note: ~~χ^2 (7, N = 1628) = 14.47, p =.043; GFI=.997, AGFI=.997; RMR=1.64.~~

Figure Captions

Figure 1. Measurement model for the Test of Behavioral Rigidity.

Figure 2. Measurement model for the cognitive ability battery.

Figure 3. Measurement model for the longitudinal factor analysis of the Test of Behavioral Rigidity.

Figure 4. Cumulated longitudinal age changes on the rigidity-flexibility factor scores (from 7-year data, N = 837).

Figure 4

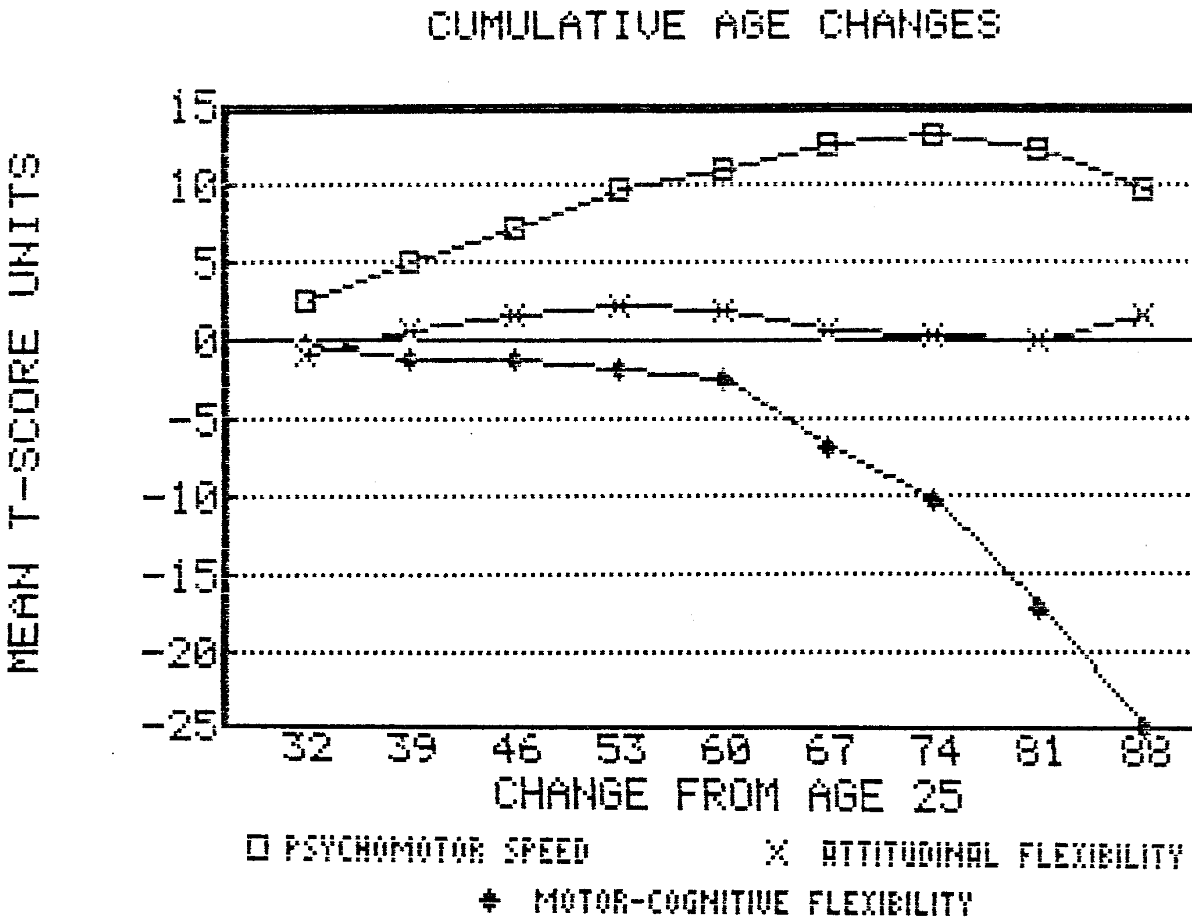
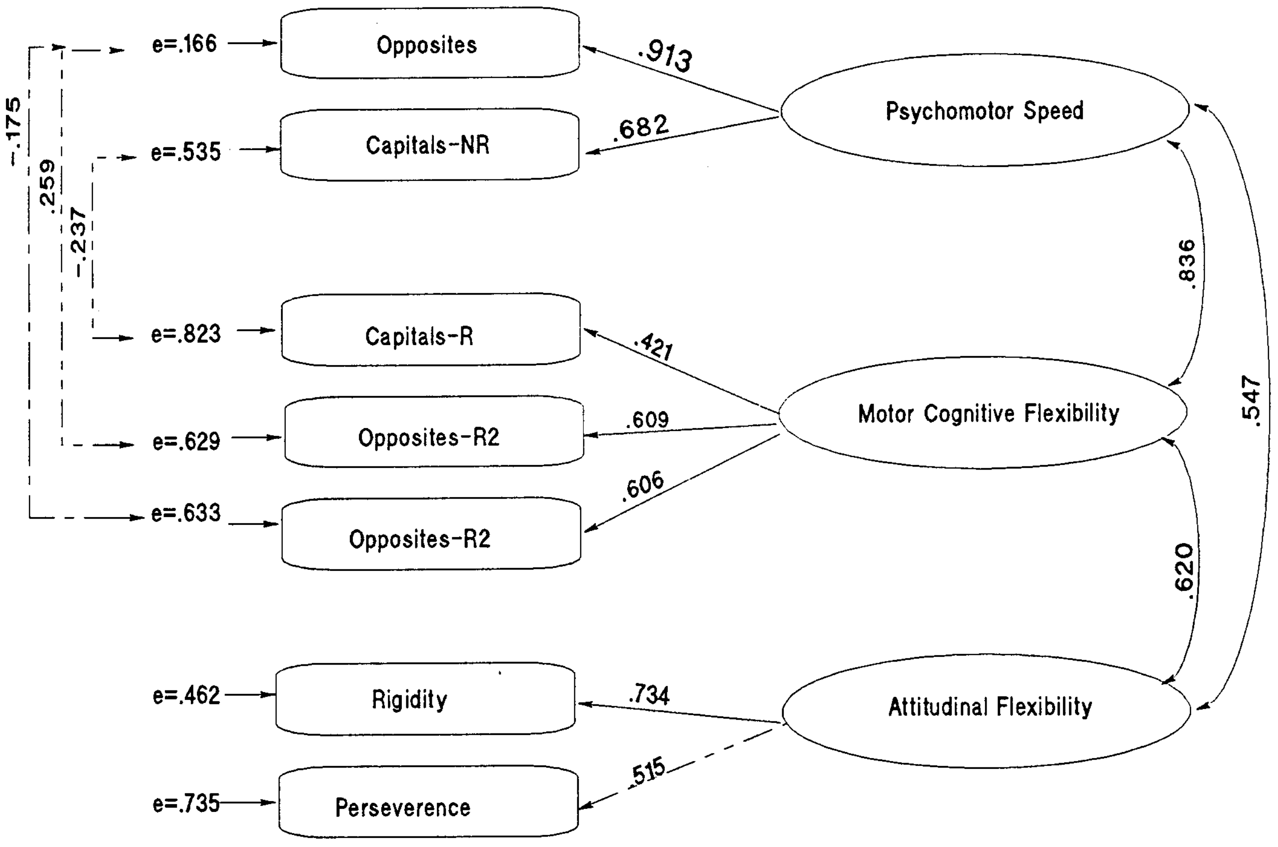

CUMULATIVE AGE CHANGES
MEAN T-SCORE UNITS
15
10
5
0
-5
-10
-15
-20
-25
32
39
46
53
60
67
74
81
88
CHANGE FROM AGE 25
□ PSYCHOMOTOR SPEED
X ATTITUDINAL FLEXIBILITY
+ MOTOR-COGNITIVE FLEXIBILITY

Figure 1

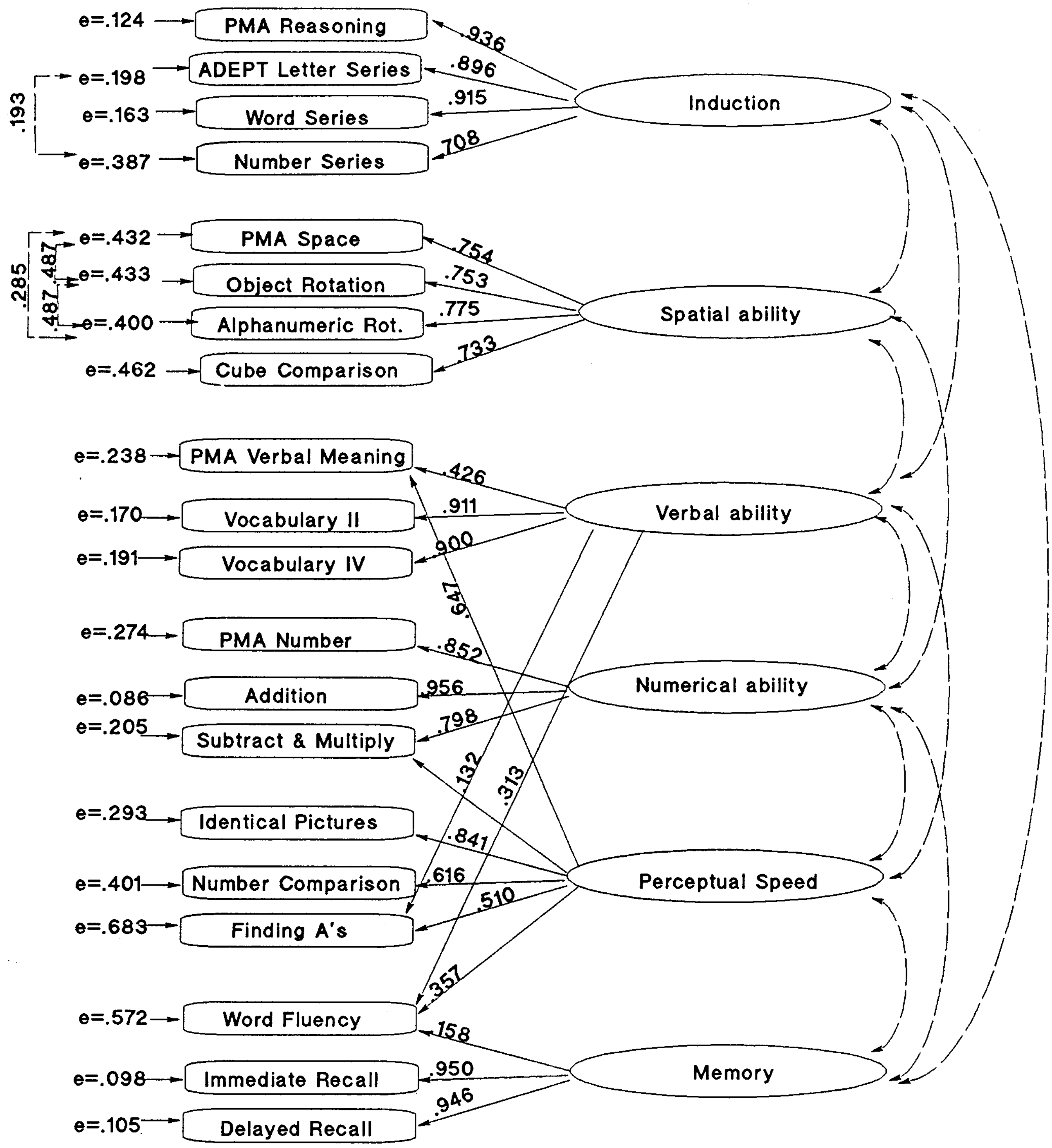
Measurement Model for the Test of Behavioral Rigidity



Note : X^2(7, N = 1628) = 14.47, p = .04; GFI = .997; AGFI = .997; RMR = 1.64

Figure 2

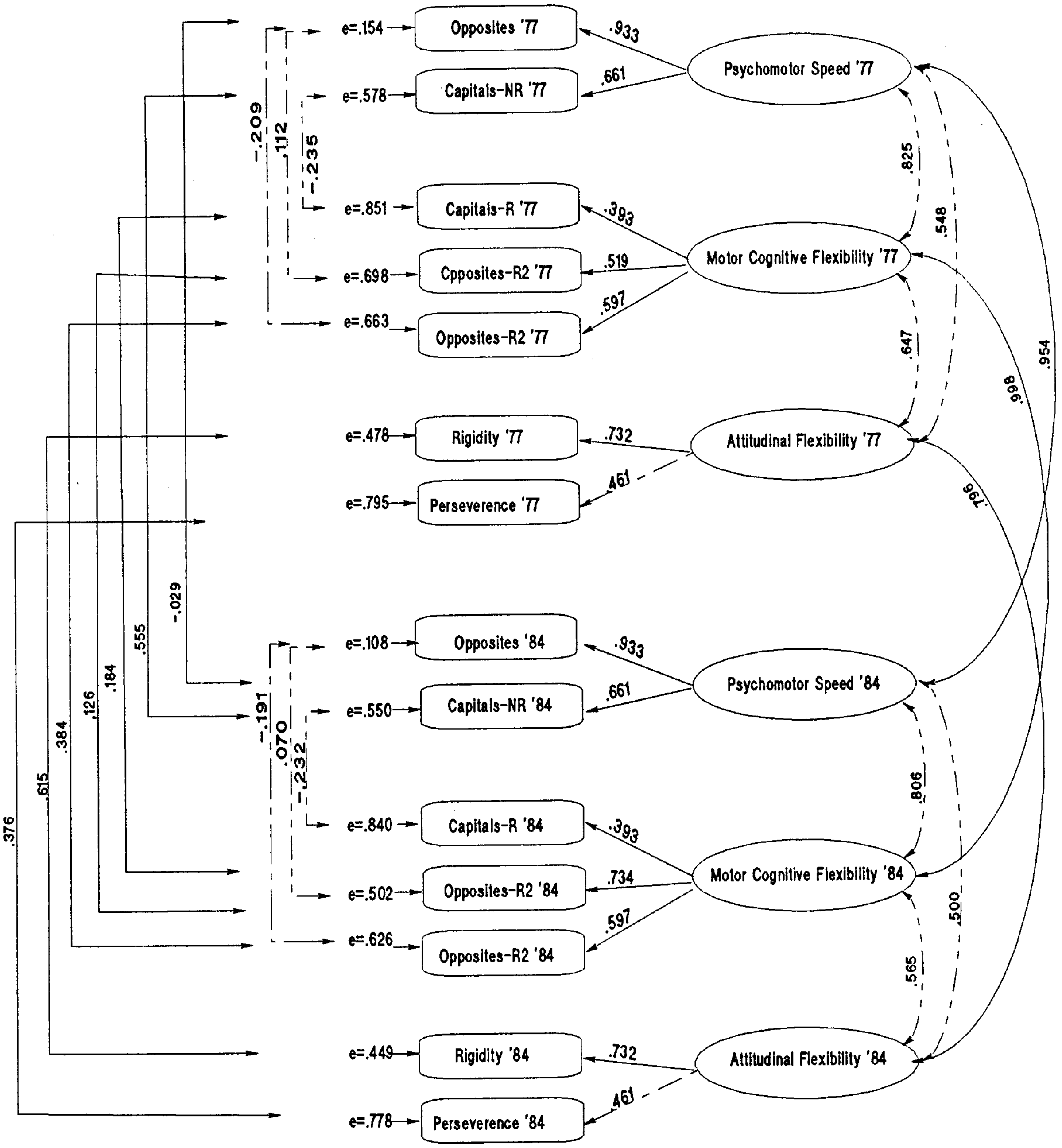
Measurement Model for the Cognitive Battery



Note : χ^2(144, N = 1628) = 746.77, p <.001; GFI = .955 AGFI = .934; RMR = 3.212

Figure 3

Longitudinal Factor Analysis for Flexibility Dimensions



Note : χ^2(53, N = 837) = 89.91, p = .001; GFI = .985, AGFI = .970; RMR = 5.094