Psychology and Aging
1991, Vol. 6, No. 3, 371–383

0882-7974/91/$3.00

Relationship Between Rigidity–Flexibility and Cognitive Abilities in Adulthood

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The interrelationship of measures of rigidity–flexibility and of psychometric intelligence is examined. The latent factors of Attitudinal Flexibility, Motor–Cognitive Flexibility, and Psychomotor Speed are derived from the Test of Behavioral Rigidity, and factors of Inductive Reasoning, Spatial Orientation, Verbal Ability, Numeric Ability, Verbal Memory, and Perceptual Speed are derived from the Thurstone Primary Mental Abilities Test and the Educational Testing Service Kit of Factor-Referenced Tests. The data base in this study comes from the fifth wave of the Seattle Longitudinal Study ($N = 1,628$; age range, 22–95 years). The Rigidity–Flexibility factors were found to be independent of the cognitive domain. Also, longitudinal stability of the factor structure of the rigidity–flexibility domain was confirmed for 837 participants tested in both 1977 and 1984.

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 multidimensional in nature. Schaie and Willis (in press) examined differential age changes and generational differences in three rigidity–flexibility dimensions. They found increasing rigidity for some of the rigidity–flexibility measures. Positive cohort effects favoring the younger participants were also discovered.

This article examines data from the Seattle Longitudinal Study (SLS) to investigate the interrelationship of measures of rigidity–flexibility and of cognitive abilities. We first seek to reconfirm the three-factor structure of the rigidity–flexibility domain (Attitudinal Flexibility, Motor–Cognitive Flexibility, and Psychomotor Speed) originally described by Schaie (1955). Next, we examine whether there is overlap between the factors of Rigidity–Flexibility and the cognitive ability factors to which Rigidity–Flexibility has been empirically related (Crowne, 1965; Kleinmuntz, 1965). To do so, we develop a six-factor measurement model of cognitive abilities. Tests marking the factor of Verbal Memory are added to a previously confirmed five-factor model that includes Inductive Reasoning, Spatial Orientation, Verbal Ability, Numeric Ability, and Perceptual Speed (Schaie, Willis, Jay, & Chipuer, 1989). We then examine the combined structure of the two domains to determine whether the three rigidity–flexibility dimensions extend beyond the cognitive ability factor space. After demonstrating the construct validity of the rigidity–flexibility factors, we proceed to examine their stability in a longitudinal sample over a 7-year period.

Developmentally oriented studies of rigidity–flexibility have assumed equivalence of factor structure of the assessment battery both within subjects across time and between different age groups of subjects 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. That is, quantitative comparisons are meaningful only if there is qualitative invariance (cf. Baltes & Nesselroade, 1973).

Thus far we have examined longitudinal factor invariance of the first 5 primary mental abilities to a second-order *g* factor (Hertzog & Schaie, 1986). Hertzog and Schaie found highly stable individual differences in the projection of the primary factors on the second-order factor over 14-year intervals. One of the critical questions addressed in this article, therefore, is whether similar stability can also be found for the dimensions of rigidity–flexibility.

Characteristics of the Data Base

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 of 20 to 70 years. The subjects were recruited 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

The analyses reported in this article are part of the doctoral dissertation work of Ranjana Dutta. An abbreviated version of this article was presented at the 10th biennial meeting of the International Society for the Study of Human Development, Jyväskylä, Finland, July 9–14, 1989. The research reported in this article was supported by National Institute on Aging Grant R37 AG08055.

We gratefully acknowledge the enthusiastic cooperation of members and staff of the Group Health Cooperative of Puget Sound and the many students, technical assistants, and colleagues in the Seattle Longitudinal Study who participated in the collection of the data base.

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were added in 7-year intervals. The sampling frame represents a broad distribution of educational and occupational levels, covering the upper 75% of the socioeconomic 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 data examined in this article include the 1,628 community-dwelling individuals (743 men and 885 women) who were examined in the fifth SLS cycle from 1983 through 1985 (see Table 1 for a breakdown by age and cohort). These individuals had an average educational level of 14.3 years (*SD* = 3.06; range, 1–20 years); and their family income averaged $23,200 (*SD* = $9,606; range, $1,000–$50,000+). The average occupational level was 6.8 (*SD* = 1.87), on a scale ranging from *unskilled* (0) to *professional occupations* (9). The most frequently represented occupations were skilled trades, clerical, sales, managerial, and semiprofessional jobs (also see Schaie, 1988). Of these individuals, 837 (389 men and 448 women) had previously been tested during the 1977 cycle of the study. All participants were in good health when tested and capable of doing pencil-and-paper tests.

The longitudinal subsample was on average 2 years older than the cross-sectional sample (*ns*) and similar as to demographic characteristics like income, education, and occupational level. *T*-test comparisons revealed that the longitudinal subgroup did not differ significantly from the cross-sectional sample on any measure.

Measurement Variables

Primary mental abilities (PMA). The test battery administered to the participants in this study included multiple measures of cognitive abilities that 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, whereas verbal ability and numeric ability stand as representatives of crystallized intelligence. Verbal memory and perceptual speed are examined as ability markers 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 2-week interval for a group of 172 subjects. A brief description of these abilities and their measures is given below:

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

1. *PMA Reasoning test.* 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.
2. *ADEPT Letter Series test.* This is a form parallel to the PMA Reasoning test.
3. *Word Series test.* 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.
4. *Number Series test.* 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. Spatial orientation is 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.

1. *PMA Space test.* 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.
2. *Object Rotation test.* 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.
3. *Alphanumeric Rotation test.* The subject is shown a letter or a 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.

4. *Cube Comparisons test.* 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 are measured by assessing the scope of a person's recognition vocabulary.

Table 1
Age and Sex Distribution of the Cross-Sectional Sample

Group	SLS cohort	Year of birth (range for cohort)	No. of subjects: Male	Female	Total	Mean age
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			743	885	1,628	59

Note. Following the convention used in all reports from the Seattle Longitudinal Study (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 (1949)	Thurstone & Thurstone (1949)	.884
	ADEPT Letter series (Form A)	Blieszner, Willis, & Baltes (1981)	.839
	Word Series	Schaie (1985)	.852
	Number Series	Ekstrom, French, Harman, & Derman (1976)	.833
Spacial orientation	PMA Space (1949)	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 (1949)	Thurstone & Thurstone (1949)	.875
	Addition (N–1)	Ekstrom et al. (1976)	.937
	Subtraction and Multiplication (N–3)	Ekstrom et al. (1976)	.943
Verbal ability	PMA Verbal meaning (1949)	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, Gilewski, & Schaie (1979)	.820
	Delayed Recall	Zelinski, Gilewski, & Schaie (1979)	.732
	PMA Word Fluency (1949)	Thurstone & Thurstone (1949)	.896

Note. PMA = Primary Mental Abilities Test; ETS = Educational Testing Service Kit of Factor-Referenced Tests; ADEPT = Adult Development and Enrichment Project-Test.

1. *PMA Verbal Meaning test.* The PMA Verbal Meaning test is a four-choice synonym test.
2. *Educational Testing Service (ETS) Kit of Factor-Referenced Tests Vocabulary test.* The ETS Vocabulary test is a five-choice synonym test.
3. *ETS Advanced Vocabulary test.* The ETS Advanced Vocabulary test is a five-choice synonym test consisting mainly of difficult items.

Numeric ability. Numeric ability is the ability to understand numerical relationships and compute simple arithmetic functions.

1. *PMA Number test.* The subject checks whether additions of simple sums are correct or incorrect.
2. *Addition test.* This is a test of speed and accuracy in adding three single- or two-digit numbers.
3. *Subtraction and Multiplication test.* This is a test of speed and accuracy with alternate rows of simple subtraction and multiplication problems.

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

1. *Immediate Recall test.* Subjects study a list of 20 words for 3½ min. They are then given an equal period of time to recall the words in any order.
2. *Delayed Recall test.* Subjects are asked to recall the same list of words as in the Immediate Recall test after an hour of intervening activities (other psychometric tests).
3. *PMA Word Fluency test.* The subject freely recalls as many words as possible according to a lexical rule within a 5-min period.

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

1. *Identical Pictures test.* The subject identifies which of five numbered shapes or pictures in a row are identical to the model at the left of the row.
2. *Finding A's test.* In each column of 40 words, the subject must identify the 5 words containing the letter *a*.
3. *Number Comparison test.* The subject inspects pairs of multidigit 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 designed to measure the three dimensions of psychomotor speed, motor–cognitive flexibility, and attitudinal flexibility (Schaie, 1955). The TBR yields seven scores from the following three subtests:

1. *Capitals test.* Adapted from Bernstein's (1924) study of quickness and intelligence, the Capitals test (*Cap*) represents the Spearmanian, or functional, approach to perseveration or rigidity. Subjects spend 2½ min copying a printed paragraph that contains some words starting with capital letters, others spelled entirely in capitals, and some starting with a lowercase letter and their remainder in capitals. In the second half of the test, subjects copy

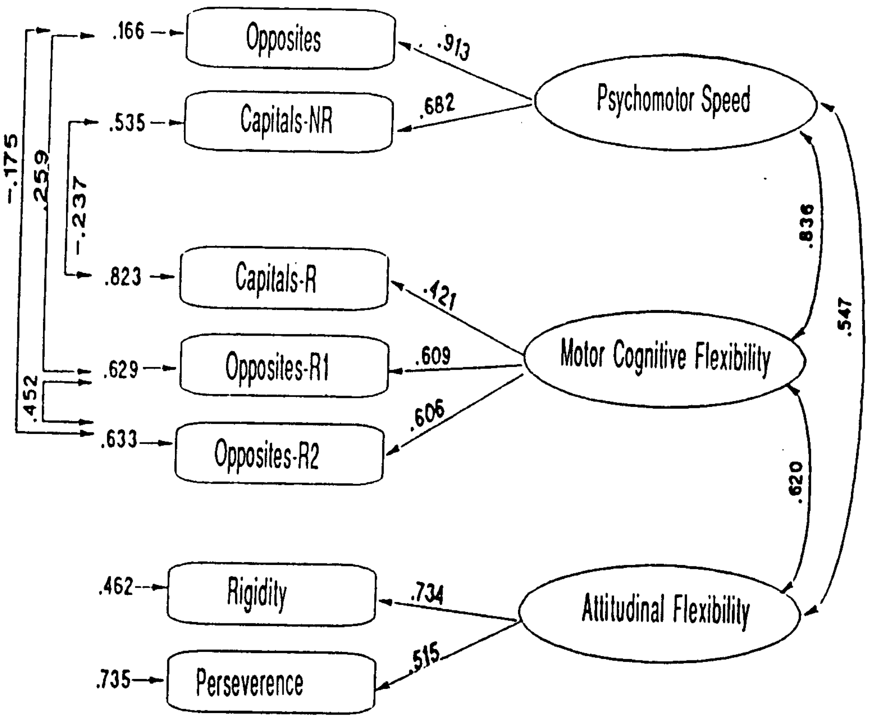

Figure 1. Measurement model for the Test of Behavioral Rigidity.

the paragraph again, but in reverse form, that is, substituting capitals for lowercase letters and lowercase 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.

2. *Opposites test (Opp).* This test was constructed following the work of Scheier and Ferguson (1952). Subjects are given 2 min 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 to which the subject responds with an antonym if the stimulus word is printed in lowercase letters, but with a synonym if the stimulus word is printed in capitals. The psychomotor speed score is the sum of correct responses in the 1st two lists (associative speed, *Opp*).

There are two motor–cognitive flexibility scores, representing the ease with which the subject shifts from synonyms to antonyms, depending on whether the stimulus word is presented in uppercase or lowercase letters. The first score involves the proportion correct in List 3 (Associative Flexibility 1, *Opp-R1*), whereas the second assesses the ratio of correct responses under the perseveration condition in List 3 to the number of correct responses under the standard condition in Lists 1 and 2 (Associative Flexibility 2, *Opp-R2*). The first motor–cognitive flexibility score (Associative Flexibility 1, *Opp-R1*) is obtained by the formula

$$\text{Opp-R1} = 100 - \frac{\text{Series 3 errors}}{\text{Series 3 total}} \times 100.$$

The second score (Associative Flexibility 2, *Opp-R2*) involves the formula

$$\text{Opp-R2} = \frac{\text{Series 3 correct}}{1/2\,(\text{Series 1 correct} + \text{Series 2 correct})} \times 100.$$

3. *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 suitable for adults obtained from the Guttman Scaling of Perseveration Scale first used by Lankes (1915; (behavioral flexibility, *P* scale).

Assessment Procedure

The measures described above were administered to all subjects in small groups, as part of a 5-hr battery spread over two assessment 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 the participants.

Model Specification and Evaluation

In this article, we first apply restricted (confirmatory) factor analysis to confirm measurement models separately to the rigidity–flexibility and cognitive ability domains. The overlap in these domains is then examined by using the combined covariance matrix. The measurement model confirmed for the rigidity–flexibility domain is then assessed longitudinally to test the hypothesis of structural invariance over a 7-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, 1984; Schaie & Hertzog, 1985, for further discussion of the technique).

Table 3
Univarate Descriptors of the Data Used in Model Building

Variable	*M*	*SD*	Skewness
N = 1,628			
PMA Reasoning	14.75	7.11	−0.05
ADEPT Letter Series	9.54	4.38	0.16
Word Series	16.53	6.36	−0.30
Number Series	5.55	3.21	0.24
PMA Space	18.18	11.31	0.22
Object Rotation	32.41	14.34	−0.42
Alphanumeric Rotation	37.24	12.74	−0.62
Cube Comparison	17.77	6.88	0.37
PMA Verbal	35.54	11.15	−0.57
Vocabulary II	28.94	5.04	−1.37
Vocabulary IV	24.45	6.56	−0.37
PMA Number	23.04	10.41	0.47
Addition	42.87	13.63	0.31
Subtraction and Multiplication	54.32	18.69	0.12
Identical Pictures	32.18	9.13	−0.19
Number Comparison	21.25	5.91	0.09
Finding *A*'s	26.06	8.05	0.69
Word Fluency	40.70	13.44	0.24
Immediate Recall	12.95	4.13	−0.24
Delayed Recall	10.82	4.84	0.04
Opposites	57.78	15.35	−0.58
Capitals	38.35	13.28	0.29
Capitals-R	66.51	19.57	0.91
Opposites-R1	87.47	18.30	−1.96
Opposites-R2	68.90	26.67	−0.05
Rigidity Scale	10.11	1.44	0.02
Perseveration Scale	4.34	1.44	−0.38
N = 837			
Opposites 77	60.83	13.95	−0.72
Capitals 77	35.39	12.05	0.35
Capitals-R 77	71.68	16.22	−0.31
Opposites-R1 77	91.81	14.01	−2.94
Opposites-R2 77	71.15	24.00	−0.21
Rigidity Scale 77	10.29	4.27	0.03
Perseveration Scale 77	4.27	1.41	−0.34
Opposites 84	58.78	14.81	−0.65
Capitals 84	38.32	12.98	0.22
Capitals-R 84	67.60	18.03	0.19
Opposites-R1 84	88.00	17.69	−1.95
Opposites-R2 84	68.61	26.45	0.03
Rigidity Scale 84	10.21	4.18	−0.01
Perseveration Scale 84	4.30	1.37	−0.25

Note. PMA = Primary Mental Abilities Test; ADEPT = Adult Development and Enrichment Project Test.

All parameters in our analyses were estimated by the maximum likelihood method. We also obtained parameter estimates for our final models by using the unweighted least squares (ULS) method in LISREL to test for substantial violations of the assumption of multivariate normality. In general, the ULS estimators are consistent without making the distributional assumption. The ULS models fit satisfactorily, and the parameter estimates did not differ markedly from those obtained by the maximum likelihood method. We split our cross-sectional sample into two random halves, one for confirmatory factor analysis with model modification and the other for confirming the modified model.

Evaluation of the models was based on overall fit indices, as well as magnitude and statistical significance of individual parameters. In the model specification stages, diagnostics such as modification indices, fitted residuals, and *q* plots of the parameters were examined.

Given our large sample sizes, the likelihood ratios become sensitive to even the most trivial discrepancies between the model and data; hence other goodness-of-fit indices were also examined. The alternate fit indices are thought to be relatively less influenced by sample size or by departures from multivariate normality than the likelihood ratio statistic. Bollen (1986, 1990) demonstrated that sample size does in fact affect these indices either directly or by affecting the means of the sampling distribution of the fit indices. However, other recent literature (see Marsh, Balla, & McDonald, 1988) has suggested that this may not be the case. A number of alternate goodness-of-fit indices have been advanced recently (see Mulaik et al., 1989) that assess different aspects of fit. For our models we examined the Bentler and Bonett (1980) normed fit indices. These indices use a zero-factor null model as a baseline to norm the less restricted models. Beside these, we also provide the LISREL GFIs, the adjusted goodness of fit, the root mean square residual, and Bollen's (1989) nonnormed fit index.

Following Sobel and Bohrnstedt's (1985) suggestion, we also used current theoretically based null models to norm our fit indices wherever possible. The Sobel-Bohrnstedt Index (SBI) provides a goodness-of-fit index that is more sensitive to improvement over what is already known about the models. A parsimony index was also calculated on the basis of the recommendations of Mulaik et al. (1989). The latter index adjusts for the goodness of fit that would result just from freeing any parameter, thus combining information regarding fit and parsimony of the model in one index. Finally, we calculated the critical *N* proposed by Hoelter (1983) to estimate the sample size on which the model, with any given fit, could be accepted.

For longitudinal factor analysis, factor models were estimated by means of the 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. Latent factors were thus assigned the metric of the variable fixed to 1 in the lambda matrix. These parameter estimates have been further rescaled to a quasi-standardized metric, using a SAS PROC MATRIX (IML) program for scaling longitudinal factor analysis. This rescaling preserves longitudinal constraints on parameter estimates but returns scaled values that are similar to standardized factor loadings and thus easier to interpret.

In the longitudinal analyses, we asked the question of whether our rigidity-flexibility dimensions remain qualitatively invariant across time. The evidence required for factorial invariance is the demonstration of the equality of unstandardized factor pattern weights (factor loadings; see Hertzog & Schaie, 1986; Meredith, 1964; Schaie & Hertzog, 1985). The concept of invariance introduced by Thurstone (1947; pp. 360–369) has been further elaborated into configural and metric invariance in factor loadings by Horn, McArdle, and Mason (1983). They have suggested that these alternate levels of invariance have different implications for the study of age changes and age differences.

Table 4
Null, Modified, and Confirmed Models for the Test of Behavioral Rigidity

Model	*df*	χ^2	GFI	AGFI	PGFI	RMR	NFI	NNFI	SBI	CN
M0S1	21	1,656.65	.566	.421	.425	92.70	—	—	—	16.91
M0S2	21	1,545.39	.597	.463	.448	88.79	—	—	—	18.06
M0ST	21	3,185.73	.583	.444	.437	90.60	—	—	—	17.56
M1S1	11	94.13	.972	.929	.382	9.23	.943	.944	—	168.75
M2S1	7	9.97	.996	.984	.249	2.13	.994	.994	.894	1,127.16[a]
M2S2	7	9.15	.997	.988	.249	1.99	.994	.994	—	1,228.09[a]
M2ST	7	14.47	.997	.988	.249	1.64	.995	.995	—	1,553.84[a]

Note. M0 = no factor null; M1 = baseline; M2 = accepted; S1 = exploratory sample (N = 814); S2 = confirmatory sample (N = 814); ST = total sample (N = 1,628); GFI = LISREL goodness of fit; AGFI = adjusted goodness of fit; PGFI = parsimonious goodness of fit; RMR = root mean square residual; NFI = normed fit index of Bentler and Bonett (1980); NNFI = nonnormed fit index of Bollen (1989); SBI = normed fit from baseline theoretical model (Sobel & Bohrnstedt, 1985); CN = critical N (Hoelter, 1983).
[a] Accepted model.

In this study we tested the best fitting model obtained from our cross-sectional analysis on longitudinal data. Changes in factor structure were examined at three levels of stringency: (a) complete metric invariance, implying that there would be no difference in the loadings and factor interrelations of our measures across time; (b) incomplete metric invariance, implying maintenance of factor pattern across time, but allowing for partial differences in the factor variances and covariances; and (c) configural invariance, requiring maintenance of factor patterns, but allowing for differences in factor loadings and factor intercorrelations. If configural invariance is not maintained across time or across different cohort groupings, then it is likely that developmental processes or cohort effects may have produced qualitative changes in factor structure. If this were the case, interpretation of quantitative age changes or age differences would 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 remains equal across time. It seems reasonable to hypothesize 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, there may be differences in the magnitude of the factor loadings for Tests A and B, even though the tests mark the same ability factor across time. In the absence of metric invariance, quantitative changes in observed scores might be uninterpretable, and instead latent factor scores would need to be used (Hertzog & Schaie, 1988).

Results

Results of our analyses are reported in four parts: (a) analyses pertaining to the structure of the TBR; (b) the structure of the cognitive abilities battery, (c) the factor structure of the covariance matrix including both the TBR and the cognitive batteries, and (d) longitudinal analyses of the rigidity–flexibility dimensions. Univariate descriptors of all observed variables are shown in Table 3.

Table 5
Null, Modified, and Confirmed Models for Cognitive Battery

Model	*df*	χ^2	GFI	AGFI	PGFI	RMR	NFI	NNFI	SBI	CN
M0S1	190	13,918.39	.181	.095	.164	44.02	—	—	—	14.02
M0S2	190	14,314.67	.179	.093	.162	44.10	—	—	—	13.66
M0ST	190	28,003.82	.180	.094	.163	43.99	—	—	—	13.96
M1S1	153	789.68	.913	.881	.665	8.63	.943	.953	—	189.07
M2S1	152	702.10	.921	.891	.667	5.01	.950	.959	.111	211.26
M3S1	152	685.89	.923	.894	.668	6.70	.951	.960	.131	216.23
M4S1	151	619.51	.929	.901	.668	4.39	.955	.963	.215	237.86[a]
M4S2	151	706.31	.921	.890	.662	4.13	.951	.959	—	208.75[a]
M4ST	151	1,144.26	.934	.908	.672	4.09	.959	.963	—	257.63[a]

Note. M0 = no factor null; M1 = baseline; M2 = free word fluency on perceptual speed; M3 = free word fluency on verbal; M4 = free word fluency on both perceptual speed and verbal; S1 = exploratory sample (N = 814); S2 = confirmatory sample (N = 814); ST = total sample (N = 1,628); GFI = LISREL goodness of fit; AGFI = adjusted goodness of fit; PGFI = parsimonious goodness of fit; RMR = root mean square residual; NFI = normed fit index of Bentler and Bonett (1980); NNFI = nonnormed fit index of Bollen (1989); SBI = normed fit from baseline theoretical model (Sobel & Bohrnstedt, 1985); CN = critical N (Hoelter, 1983).
[a] Accepted model.

Table 6
Rescaled Solution for the Accepted Cognitive Model

Variable	Inductive reasoning	Spatial orientation	Verbal ability	Numeric ability	Perceptual speed	Verbal memory	Unique variance
			Factor loading				
PMA Reasoning	.934						.128
ADEPT Letter Series	.901						.188
Word Series	.913						.167
Number Series	.790						.375
PMA Space		.847					.282
Object Rotation		.892					.204
Alphanumeric Rotation		.861					.259
Cube Comparison		.664					.560
PMA Verbal Meaning			.411		.650		.240
ETS Vocabulary			.908				.176
Advanced Vocabulary			.903				.185
PMA Number				.854			.270
Addition				.944			.109
Subtraction and Multiplication				.893			.203
Identical Pictures					.836		.302
Number Comparison				.243	.611		.399
Finding *A*'s					.560		.687
Word Fluency			.302		.360	.158	.572
Immediate Recall						.950	.097
Delayed Recall						.946	.105
			Factor intercorrelations				
Inductive reasoning	—						
Spatial orientation	.770	—					
Verbal ability	.471	.253	—				
Numeric ability	.559	.417	.368	—			
Perceptual speed	.876	.775	.318	.567	—		
Verbal memory	.645	.473	.370	.355	.672	—	

Note. $\chi^2(151, N = 1{,}628) = 1{,}144.26$, $p < .001$. LISREL goodness of fit = .934; adjusted goodness of fit = .908; root mean square residual = 4.09; parsimonious goodness of fit = .672; and critical $N = 257.63$. PMA = Primary Mental Abilities Test; ETS = Educational Testing Service Kit of Factor-Referenced Tests; ADEPT = Adult Development and Enrichment Project Test.

Confirmatory Factor Analyses for the TBR

The initial model for the TBR was based on the factor structure derived from prior analyses on two independent cross-sectional data sets comprising 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 lives (see Figure 1).

Covariances of the seven scores obtained from the TBR were analysed. The variances of the factors were fixed to 1.0, and the loadings of the seven scores and the intercorrelations among the three factors were estimated (Model 1; M1). Several of the TBR scores are derived from the same subtests, and their errors would therefore be expected to correlate. For example, the Capitals test yields a speed score (Caps-NR) and a flexibility score (Caps-R). Similarly, two flexibility scores are derived from the Opposites test, using different weights. Four elements in the error matrix corresponding to these correlations were therefore freed (Model 2; M2) and the model accepted. This model was then confirmed on the other half of the sample (S2), as well as on the total sample (ST) as shown in Table 4.

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 initial model was based on prior analyses, with the addition of a Memory factor (Schaie, Willis, Hertzog, & Schulenberg, 1987; Schaie et al., 1989). This Memory factor was marked by observed scores on tests of immediate and delayed recall and on word fluency. The 20 cognitive measures were modeled as indicators of six oblique factors (M1). This model had good overall fit but revealed stress in the specification of word fluency. In our battery, this measure shared common vari-

Table 7
Null, Modified, and Confirmed Models for Combined Batteries

Model	*df*	χ^2	GFI	AGFI	PGFI	RMR	NFI	NNFI	SBI	CN
M0S1	351	17,123.13	.163	.099	.151	56.14	—	—	—	19.78
M0S2	351	17,560.47	.162	.098	.150	56.37	—	—	—	19.31
M0S3	351	34,309.82	.163	.099	.151	56.17	—	—	—	19.76
M1S1	280	979.33	.918	.889	.680	5.12	.943	.962	—	266.55[a]
M1S2	280	1,095.73	.909	.877	.673	5.66	.938	.958	—	238.34[a]
M1ST	280	1,775.41	.924	.897	.684	5.08	.948	.957	—	294.13[a]
M2S1	288	1,116.62	.907	.878	.691	5.49	.935	.957	—	240.12
M2S2	288	1,217.14	.899	.867	.685	5.93	.931	.954	—	220.38
CHS1	1	137.3	—	—	—	—	—	—	—	—
CHS2	1	121.4	—	—	—	—	—	—	—	—

Note. M0 = no factor null; M1 = baseline; M2 = accepted model with nine factors; M3 = tested model with eight factors; S1 = exploratory sample (N = 814); S2 = confirmatory sample (N = 814); ST = total sample (N = 1,628); GFI = LISREL goodness of fit; AGFI = adjusted goodness of fit; PGFI = parsimonious goodness of fit; RMR = root mean square residual; NFI = normed fit index of Bentler and Bonett (1980); NNFI = nonnormed fit index of Bollen (1989); SBI = normed fit from baseline theoretical model (Sobel & Bohrnstedt, 1985); CN = critical N (Hoelter, 1983); CH = change in nested models (M2–M1).
[a] Accepted model.

ance with measures of Perceptual Speed (M2) and Verbal Ability (M3) and was allowed to load on these factors freely. The loadings on both Verbal Ability and Perceptual Speed were significant and higher than that for memory, and this modification substantially improved the overall fit as well (M4). (See Table 5).

The accepted model was characterized by high and statistically significant loadings of all variables on their associated primary ability factors, relatively high communalities, and correspondingly low uniquenesses (see parameter estimates provided in Table 6).

Factor Analyses for the Combined Batteries

To examine the relationship between the TBR and the cognitive battery, we analyzed their common covariance matrix. Exploratory factor analysis of this matrix revealed that 8–10 factors were plausible on the basis of indices such as the proportion of variance explained, the number of eigenvalues greater than 1.0, and examination of the scree plot, as well as the Tucker and Lewis (1973) reliability coefficient.

Our first hypothesized model (M1 in Table 7) specified nine factors and included the six cognitive factors and three flexibility factors that were confirmed in the analyses reported above. This model specifies maintenance of these factor-pattern structures when the batteries are combined. Correlated errors estimated in the TBR analyses were also allowed to be correlated in this model, and the factor intercorrelations were left free to be estimated.

This nine-factor model fit the data very well, maintaining the structure of the original batteries, with comparable parameter estimates and factor intercorrelations. Cross-battery correlations were closely examined and three high correlations identified. The Psychomotor Speed and Motor–Cognitive Flexibility factors correlated highly with Inductive Reasoning, and Perceptual Speed correlated highly with Psychomotor Speed. Because our exploratory analyses did not rule out the possibility of an eight-factor solution, and given our highest correlation between the two speed factors, we tested for a model combining them into one factor. A nested eight-factor model was specified by setting the correlation between Perceptual Speed and Psychomotor Speed equal to 1.00 and setting their correlations with other factors equivalent. This model had a significantly worse fit and was not acceptable, $\Delta\chi^2(8, N = 814) = 137.29$, $p < .01$, in Sample 1 and $\chi^2(8, N = 814) = 121.41$, $p < .01$, in Sample 2. Furthermore, the eight-factor model was characterized by increases in factor correlations without plausible theoretically based explanations. (See Table 8 for parameter values of the accepted model.)

Longitudinal Analyses of the Rigidity–Flexibility Measures

Structural analyses. 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. The model included the 14 × 14 covariance matrix of Time 1 and Time 2 scores, with the same three-factor dimensions of the TBR for both occasions. Six factors were specified, and their intercorrelations across time were freely estimated. To assess configural invariance, the loadings of the measures on the corresponding factors were left free to vary over time. We hypothesized in advance that this model would require 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 excellent fit (see Table 9), indicating that configural invariance had been attained. The latter level of invariance, which has been

Table 8
Rescaled Solution for the Combined Rigidity–Flexibility and Cognitive Ability Battery

Variable	Inductive reasoning	Spatial orientation	Verbal ability	Numeric ability	Perceptual speed	Memory	Psycho-motor speed	Motor–cognitive flexibility	Attitudinal flexibility	Unique variance
				Factor loadings						
PMA Reasoning	.933									.130
ADEPT Letter Series	.900									.190
Word Series	.914									.164
Number Series	.791									.375
PMA Space		.848								.281
Object Rotation		.893								.202
Alphanumeric Rotation		.860								.261
Cube Comparison		.663								.560
PMA Verbal			.413		.647					.244
Vocabulary II			.903							.185
Vocabulary IV			.907							.177
PMA Number				.853						.273
Addition				.944						.109
Subtraction and Multiplication				.794						.200
Identical Pictures					.852					.291
Number Comparison				.251	.601					.405
Finding *A*'s					.542					.707
Word Fluency			.305		.400	.131				.553
Immediate Recall						.950				.097
Delayed Recall						.946				.105
Opposites							.872			.239
Capitals							.721			.481
Capitals–R								.391		.847
Opposites–R1								.626		.608
Opposites–R2								.634		.598
R Scale									.761	.421
P Scale									.496	.754
				Factor intercorrelations						
Inductive Reasoning	—									
Spatial Orientation	.769	—								
Verbal ability	.470	.253	—							
Numeric ability	.560	.417	.368	—						
Perceptual speed	.875	.774	.313	.563	—					
Memory	.645	.472	.370	.355	.672	—				
Psychomotor Speed	.863	.665	.557	.667	.913	.663	—			
Motor cognitive Flexibility	.906	.811	.507	.499	.866	.637	.840	—		
Attitudinal Flexibility	.546	.418	.423	.255	.531	.454	.553	.597	—	

Note. χ^2 (280, N = 1,628) = 1,775.41, $p < .001$. LISREL goodness of fit = .924; adjusted goodness of fit = .897; root mean square residual = 5.08; parsimonious goodness of fit = .684; and critical N = 294.13. PMA = Primary Mental Abilities Test; ADEPT = Adult Development and Enrichment Project Test.

termed the *practical scientist's concept of invariance* (Horn et al., 1983) implies that the same factors are identified at both occasions on which the observed variables load in the same pattern.

We next tested hypotheses with more stringent specifications of cross-occasion invariance for the parameter matrices. To evaluate the hypothesis of complete metric invariance, the regression weights and factor variance–covariance structure were fixed equal across time. This model fit the data adequately and

Table 9
Longitudinal Factor Analysis for the Test of Behavioral Rigidity

Model	*df*	χ^2	GFI	AGFI	PGFI	RMR	NFI	NNFI	CN
M0	91	5,567.98	.387	.293	.335	83.00	—	—	18.13
M1	47	79.02	.987	.971	.442	4.60	.986	.987	675.70
M2	57	150.32	.976	.956	.530	12.41	.973	.975	420.34[a]

Note. M0 = no factor null; M1 = configural invariance; M2 = metric invariance (*N* = 837); GFI = LISREL goodness of fit; AGFI = adjusted goodness of fit; PGFI = parsimonious goodness of fit; RMR = root mean square residual; NFI = normed fit index of Bentler and Bonett (1980); NNFI = nonnormed fit index of Bollen (1989); and CN = critical *N* (Hoelter, 1983);
[a] Accepted model.

was accepted (see Figure 2 for overall fit and parameter estimates).

The standardized solution revealed that the stability coefficients for the latent variables for Psychomotor Speed and Motor–Cognitive Flexibility were over 0.95, and the stability for Attitudinal Flexibility was 0.80. Thus, individual differences on the 1st two flexibility factors were almost perfectly preserved over a 7-year retest interval.

Discussion and Conclusion

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

As the first step in this enterprise, we reconfirmed the three-dimensional structure of the TBR 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 took advantage of LISREL procedures to fit the hypothesized parameters and the error structure on a large sample that represents the adult age range from the 20s to the 80s. This analysis permitted us to accept the original model with an excellent fit, provided we allow for the intercorrelation 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 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 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 either of 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 on the other.

Because the factor intercorrelations obtained in the nine-factor model were fairly high for at least three pairs of latent variables, we used nested modeling to test whether a more parsimonious model could be obtained by combining factors. Thus, a single-speed factor was tested against the two-speed factor model. This model was found unacceptable. The likelihood ratio for overall fit increased significantly, as did factor intercorrelations between other factors for which there is no sound theoretical rationale. Consequently, the nine-factor model seems most appropriate. However, the high factor intercorrelations require further analytic and theoretical investigation. It is conceivable that both Motor–Cognitive Flexibility and Psychomotor Speed might be markers of higher order factors of intelligence such as Fluid Intelligence (Gf) and Response Speed, as suggested by Stankov's (1988) work related to attentional flexibility. Another, more plausible reason for these high correlations could be that our flexibility constructs are marked more sparsely, as compared with the ability constructs. If we had more markers for the former constructs, they might possibly occupy a more distinct factor space. With more extensive alternate models for second-order factor analysis, we might be in a better position to evaluate this issue. Until then, we accept the more differentiated nine-factor model as our final model.

The correlations of Attitudinal Flexibility with cognitive abilities are quite another matter. Here, too, our markers are a subset of those used in more personality-oriented cognitive-style batteries, such as those of field independence (Witkin, Dyk, Faterson, Goodenough, & Karp, 1962), dogmatism (Rokeach, 1960), and openness to experience (McCrae & Costa, 1980). As it stands, we are specifically sampling those elements of the rigidity–flexibility domain that we believe are closely related to cognitive functioning.

We have also examined the possibility that covariation among the latent variable of Attitudinal Flexibility, and other abilities could be an artifact of the wide age range in our cross-sectional sample. We proceeded to test this by examining the fit of our nine-factor combined model on subgroups of different ages. We formed three age subgroups from our total cross-sectional sample: young (*N* = 437; mean age = 37.71; range, 20–49 years; Seattle cohorts = 1–4), middle-aged (*N* = 749; mean age = 61.03; range, 50–70 years; Seattle cohorts = 5–7), and old adults (*N* = 442; mean age = 77.20; range, 71–95 years; Seattle cohorts = 8–11). The baseline model was set up, specifying invari-

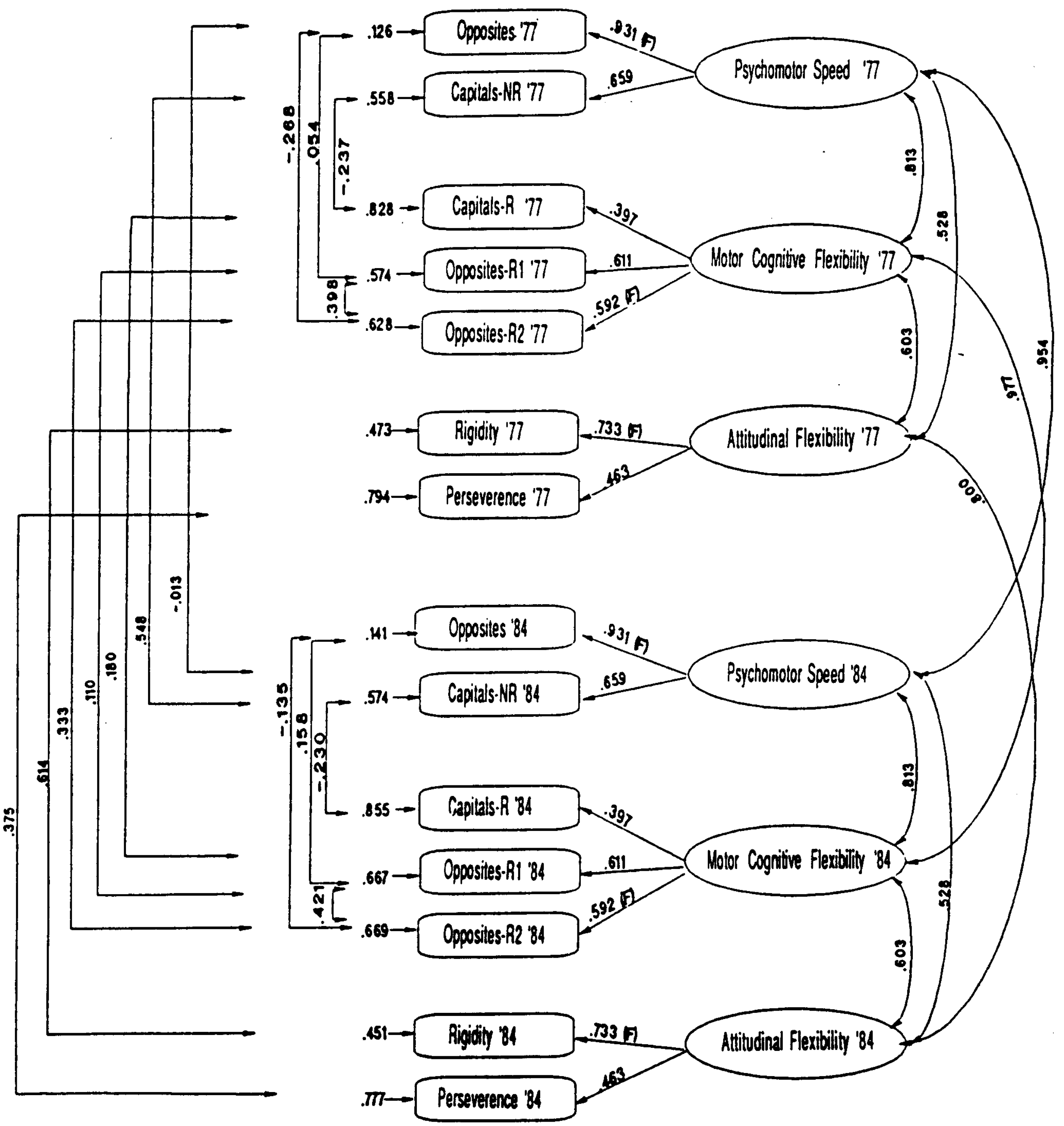

Figure 2. Measurement model for the longitudinal factor analysis of the Test of Behavioral Rigidity.

ant loadings and factor intercorrelations. Against this model, we tested a nested model allowing factor correlations of Attitudinal Flexibility with eight other factors to be freely estimated. The difference between the two models as assessed by a likelihood ratio was not significant. Assessment of individual parameters within each age group show no discernible age trend, although there are some fluctuations.

Having established the distinct nature of the rigidity–flexibility domain, we next investigated its stability over a 7-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 covariances. We were able to accept metric invariance, thereby implying 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 (cf. Schaie & Willis, in press). It should be noted, of course, that our analyses cover an extensive age range. More fine-grained analyses of subsamples with limited age ranges are likely to shed a different light on age-specific changes in parameters.

On the basis of the analyses reported here, we conclude that the three rigidity–flexibility dimensions maintain structural identity distinct from the primary mental abilities even in a combined covariance analysis. Furthermore, there is evidence of qualitative stability of these dimensions over time.

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Received February 16, 1990
Revision received December 26, 1990
Accepted February 7, 1991 ■