EFFECTS OF COGNITIVE TRAINING UPON PRIMARY MENTAL ABILITY STRUCTURE

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Abstract

This paper reports results of the first empirical test, as far as we know, of the assumption of structural invariance of latent constructs from pre- to posttest in cognitive training research on the elderly. 401 participants of the Seattle Longitudinal Study aged over 62 years received a 5-hour test battery at pre- and post-test that included 16 ability tests, marking the 5 primary abilities of Spatial Orientation, Inductive Reasoning, Numerical Ability, Verbal Ability, and Perceptual Speed. 229 of our subjects received 5 hours of individual training on either Spatial Orientation or Inductive Reasoning. Restricted factor analysis using the LISREL algorithm was used to test the hypothesis of measurement equivalence across test occasions, separately for the controls and for each of the training groups. The regression of observable marker variables on their latent ability factors was found to be virtually undisturbed by test-retest effects. When ability-specific cognitive training intervenes, no structural change is observed for abilities not subject to intervention. However, slight shifts occurred in the optimal regression weights for the different markers for the training target ability.

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Introduction

During the past few years there has been a growing interest in research that investigates the question whether the cognitive performance of older adults can be improved by means of training interventions. Such training may be directed towards remediating clearly identified deficit (cf. Schaie & Willis, in press; Willis, 1985), or towards improving the performance of elderly persons with unknown prior ability status (Baltes & Willis, 1982; Sterns & Sanders, 1980). In all these studies the primary concern is not to prove that it is possible to improve subjects' performance on some measure by "teaching the test," but rather to show that there has been training gain on a more general latent construct or ability factor. To attain this objective it is generally necessary to design a transfer-of-training type study that assesses variables that are hypothesized to benefit from the proposed training regime as well as others that should not improve if training is ability-specific. Assessment of the convergent and divergent validity of the training paradigm at the ability level, moreover, requires multiple markers (observed variables) for all of the abilities to be included in the study.

A critical assumption that underlies the evaluation of the effects of cognitive training research in the elderly at the ability level is the supposition that the projection of the observed marker variables upon the latent ability factors of interest remain equivalent from pre- to posttest. If this assumption is true, then training gains can be interpreted unambiguously. That is, training can be interpreted as increasing levels of performance without altering the nature of the performance. If the assumption is false, then it is possible that the intervention many have produced change in a bility structure, and estimates of level changes could be biased. For example, differential near transfer effects of training could change the factor loadings for one or more of the ability markers. More seriously even, changes in structure could obscure training gains at the factor level that would have been observed had the structure remained invariant. The hypothesis that factorial invariance has been maintained across the training intervention can best be tested by applying methods of restricted factor analysis, such as the LISREL algorithm (Joreskog & Sorbom, 1984). This paper reports, as far as we know, the first empirical test of the assumption of measurement equivalence from pre- to posttest in a cognitive training study.

Method

Our sample consisted of 401 participants (177 men and 224 women) over the age of 62 years (M = 72.5; Range = 62 to 95) in the Seattle Longitudinal Study (SLS) since 1975 or earlier (Schaie, 1983). All subjects received a 5-hour ability test battery at pre- and posttest that included 16 ability tests, marking the five primary mental abilities of Inductive Reasoning, Spatial Orientation, Perceptual Speed, Numerical Ability, and Verbal Ability. See Table 1. Two hundred and twenty-nine of our subjects received five hours of individual cognitive training on either Inductive Reasoning (N = 111) or on Spatial Orientation (N = 118). The remaining 172 subjects were testing-only control. One hundred and seventy subjects (42.4% of sample) had remained stable on the training target ability over a nine to fourteen year period, while 231 subjects (57.6%) had declined significantly on one or both of the abilities.

Insert Table 1 about here

The evaluation of equivalence in the factor structure of the psychometric battery in the different training groups was conducted by using LISREL VI (Joreskog & Sorbom, 1984) to perform simultaneous, multiple group, confirmatory factor analyses (see Joreskog, 1971, and Schaie & Hertzog, 1985, for a further discussion of the technique).

Results and Discussion

The hypothesis of structural invariance across cognitive training intervention in an elderly sample was investigated in this study by means of restricted factor analysis using the LISREL paradigm. A five-factor measurement model was first identified on the basis of the pretest data for all subjects. See Table 2. Next, the equivalence of factor structure was tested across sub-sets of subjects that had declined or remained stable, and across sub-sets aggregated by gender. Factorial invariance was tested with a model that constrained factor loadings and factor correlations across groups. In both instances, stability status and gender, factorial invariance across groups was found to be acceptable.

Insert Table 2 about here

Having demonstrated structural invariance over time in the control group, an isolated stability model (i.e., one that permits only autocorrelated but no cross-lagged regression coefficients) was then tested across the pre- and posttest data. Stability coefficients for the ability factors were above .90, and ability measures at pretest predicted approximately 97 percent of the individual differences variance at posttest. The remaining variance at posttest was accounted for by a slight increase in the concurrent correlation of two ability factors (Perceptual Speed and Numerical Ability) at posttest, most likely occurring as a consequence of shared mean

increments due to strong practice effects on the marker tests defining these abilities (see Table 3 and Figure 1).

Insert Figure 1 and Table 3 about here

The same model was next tested separately for each of the groups that received the training intervention. The isolated stability model did not obtain the optimal fit under either training conditions, but here too stability coefficients were in excess of .90. The stability coefficients from pre- to posttest were only slightly lower for the Inductive Reasoning and Spatial Orientation training groups. The perturbations in the projections of the observed variables upon the latent ability factors introduced by training, moreover, seemed to be specific to the primary ability on which subjects were trained, were of small magnitude, and did not substantially affect factor patterns or any of the target-ability extraneous observable-latent relationships. For the Induction training group an improved fit could be obtained when the across occasion constraints upon the Word Series factor loadings was relaxed. Further improvement was obtained when the a regression path was allowed from Perceptual Speed at pretest to Induction at Posttest. For the Space training group, similarly, an improved fit occurred when the across occasion constraint was relaxed for the Object Rotation factor loadings. Minor improvements of fit in this group also obtained when reciprocal regression paths were allowed between Perceptual Speed and Verbal Ability from pre- to posttest.

Insert Figures 2 and 3 about here

What are the implications of these findings for studies of cognitive training in the elderly? First of all it appears that differential effects of the training procedure upon the various marker variables, usually referred to as "near transfer," had consequences for the observable/latent relationship for some but not for other markers of the target training ability at posttest. In both instances where significant change in optimal factor loadings occurred at posttest in the training group (but not in the controls) the stimuli involved were the most "concrete" markers of the target ability. It is conceivable that training may have led to increasingly routinized response on these variables, somewhat reducing their contribution as a marker of the latent ability.

A second major finding of this study suggests that the regression of observed marker variables on their latent ability factors is virtually undisturbed by test-retest effects over brief test intervals (two to four weeks in our case) when no ability-specific intervention occurs between test occasions. When ability-specific cognitive training intervenes, no structural changes are observed for those abilities that were not subject to intervention (far transfer). However, slight shifts may occur in the optimal regression weights of the different markers for the training target ability. This finding suggest that training studies that wish to assess training effects at the latent ability level should include procedures such as those reported here. Factor regression weights used to estimate factor scores at pre- and posttest can then be separately estimated to assure equivalence of ability factors across occasions.

In our study, regression weights computed for the best fitting model were only trivially different from those estimated on the basis of the best-fitting pretest model across all training groups. It is noteworthy, however, that both retest and training result in increased variability for the latent variables. In effect this means that practice and other interventions have counter-intuitively increased rather than reduced individual differences in cognitive performance. As the analysis of changes in <u>level</u> of performance has shown (cf. Schaie & Willis, in press), most of our subjects gained at least somewhat from training, although there were wide individual differences in the magnitude of change. Nevertheless, changes in the subjects' relative position within their reference population were confined to a limited region within the distribution of individual differences, which as a whole tended to "fan out" somewhat at posttest. It is important to note, however, that the remarkable stability shown in our study may simply reflect that we were operating in one of the best-defined sectors of the ability domain with measures having optimal psychometric characteristics. Other investigators should therefore be most cautious in <u>not</u> interpreting our findings as providing sufficient reassurance that they can safely ignore the need to apply procedures such as those described here in order to justify their invariance assumptions.

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Copies of an extended report containing further technical details on the analysis and tables of factor loadings, unique variances, unique autocorrelations, factor covariances, and unstandardized regression coefficients may be obtained by writing to to K. Warner Schaie, Department of Individual and Family Studies, S-110 Human Development Building, The Pennsylvania State University, University Park, PA 16802.

Table 1

Intellectual Abilities Measurement Battery

Primary Ability	Test	Source
Inductive Reasoning	PMA Reasoning	Thurstone, 1948
	ADEPT Letter Series (Form A)	Blieszner, Willis, & Baltes, 1981
	Word Series	Schaie, 1985
	Number Series	Ekstrom, French, Harman, & Derman, 1976
Spatial Orientation	PMA Space	Thurstone, 1948
	Object Rotation	Schaie, 1985
	Alphanumeric Rotation	Willis & Schaie, 1983
Perceptual Speed	Finding A's	Ekstrom et al, 1976
	Number Comparison	Ekstrom et al, 1976
	Identical Pictures	Ekstrom et al, 1976
Numerical Ability	PMA Number	Thurstone, 1948
	Addition	Ekstrom et al., 1976
	Subtraction & Multiplication	Ekstrom et al., 1976
Verbal Ability	PMA Verbal Meaning	Thurstone, 1948
	Vocabulary II	Ekstrom et al., 1976
	Vocabulary IV	Ekstrom et al., 1976

Table 2

Specification of the Factor Loading Pattern Matrix

for the Accepted Measurement Model

Variable	Induction	Space	Perc. Speed	Number	Verbal
	Ability Factor				
PMA Reasoning	1[a]				
ADEPT Letter Series	1				
Word Series	1				
Number Series	1				
PMA Space		1[a]			
Object Rotation		1			
Alphanumeric Rotation		1			
Finding A's			1		
Number Comparison			1[a]	1	
Identical Pictures			1		
PMA Number				1[a]	
Addition				1	
Subtraction & Multiplication				1	
PMA Verbal Meaning			1		1
Vocabulary II					1[a]
Vocabulary IV					1

Note. A "1" indicates that the given variable loads on that factor and a blank indicates that the given variable does not load on that factor. The Phi matrix is symmetrical and free, the Theta matrix is diagonal. [a]To identify the metric of each factor, these elements were fixed to 1.00.

Table 3

Rescaled Solution for the Accepted Pretest-Posttest Measurement Model for the Control Group

Variable	Factor Loadings[a] Induction	Space	Perc. Speed	Number	Verbal	Unique Variance Pretest	Posttest	Unique Auto-Correl.
PMA Reasoning	.939					.102	.132	.156
ADEPT Letter Series	.890					.255	.162	.332
Word Series	.894					.202	.200	.387
Number Series	.791					.390	.359	.573
PMA Space		.823				.322	.323	.557
Object Rotation		.861				.301	.218	.571
Alphanumeric Rotation		.859				.296	.229	.386
Finding A's			.606			.636	.629	.707
Number Comparison			.715	.144		.317	.332	.597
Identical Pictures			.832			.297	.316	.567
PMA Number				.912		.166	.172	.343
Addition				.943		.121	.100	.543
Subtraction & Multiplication				.901		.202	.177	.746
PMA Verbal Meaning			.631		.440	.205	.152	.379
Vocabulary II					.888	.286	.121	.170
Vocabulary IV					.910	.178	.167	.724

Ability Factor

Factor	Pretest Induction	Space	P. Speed	Number	Verbal	Posttest Induction	Space	P. Speed	Number	Verbal
Pretest										
Induction	-									
Space	.675	-								
P. Speed	.777	.736	-							
Number	.687	.584	.689	-						
Verbal	.631	.298	.381	.552	-					
Posttest										
Induction	.978	.662	.763	.724	.674	-				
Space	.631	.961	.752	.579	.286	.628	-			
P. Speed	.820	.706	.994	.714	.456	.801	.729	-		
Number	.669	.540	.657	.987	.556	.717	.556	.704	-	
Verbal	.606	.284	.387	.510	1.001	.648	.279	.450	.572	-

[a]Since the accepted measurement model included the factor loadings being set equal over time, this matrix was identical for both pretest and posttest.

FIGURE 1

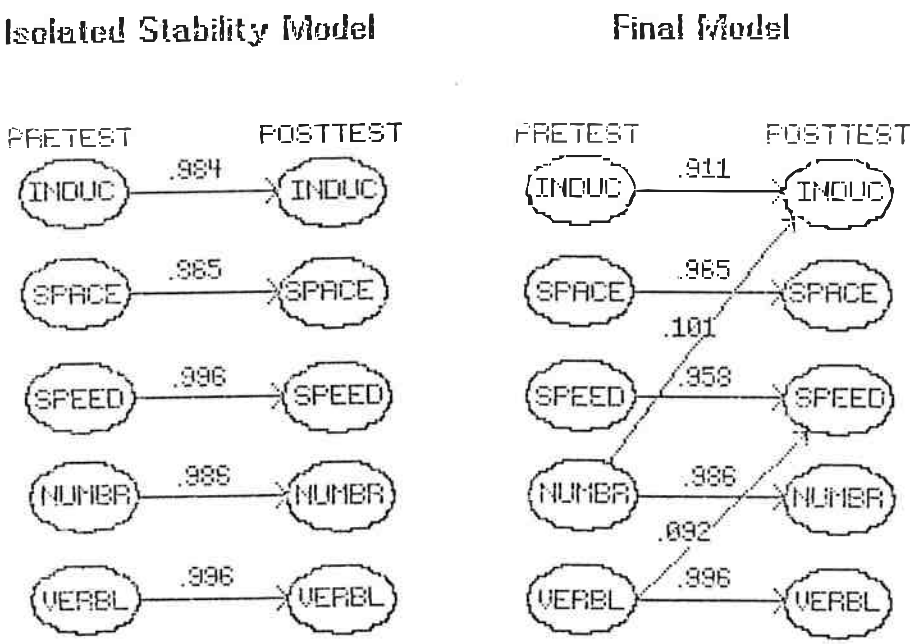

Figure 1. Standardized stability and cross-lagged coefficients for the isolated stability and final models estimated for the control group.

FIGURE 2

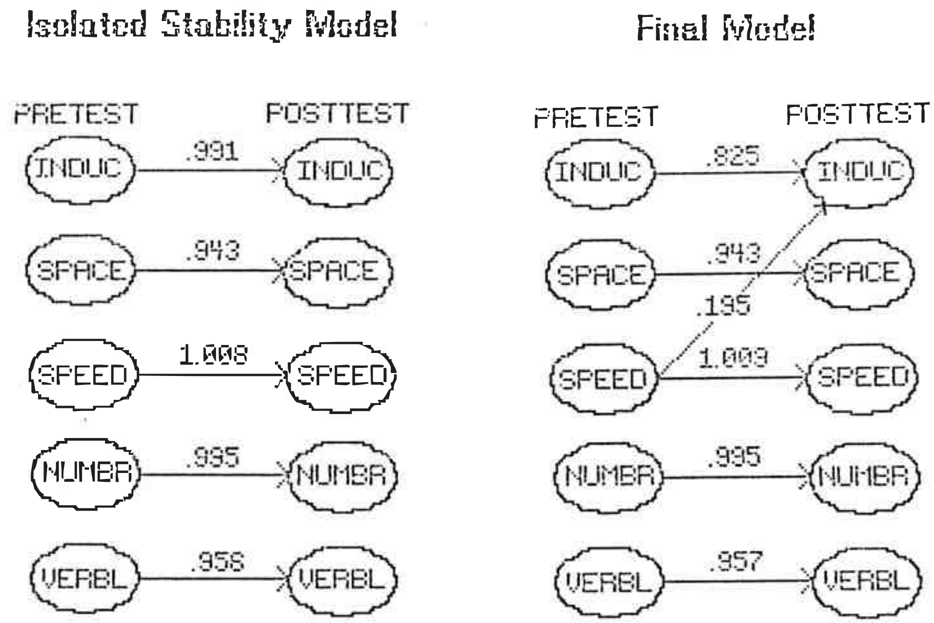

Figure 2. Standardized stability and cross-lagged coefficients for the isolated stability and final models estimated for the induction training group.

FIGURE 3

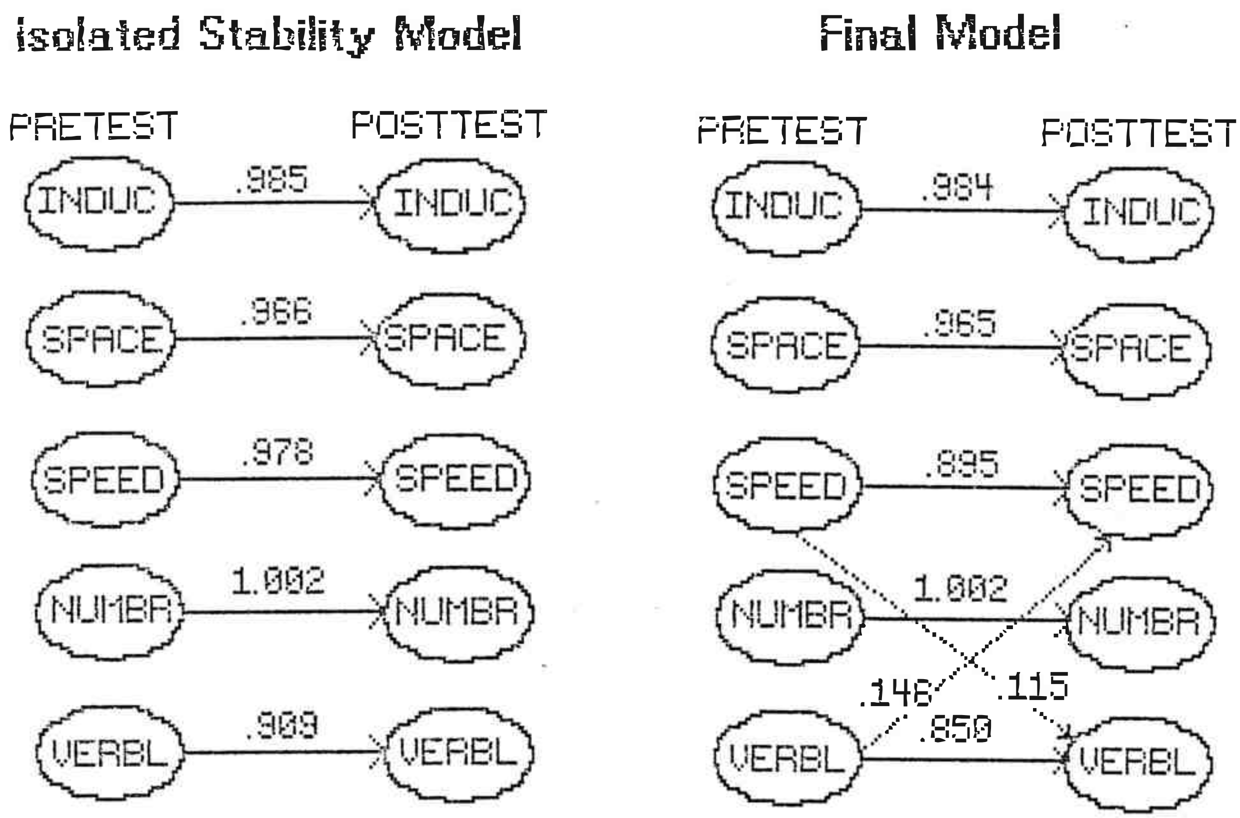

Figure 3. Standardized stability and cross-lagged coefficients for the isolated stability and final models estimated for the space training group.