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AUTHOR Hattie, John; Fitzgerald, Don

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ABSTRACT

Four alternative theoretical models of intellectual competence were assessed, using confirmatory factor analysis to account for the correlation patterns derived from Wechsler intelligence tests. It was argued that the difference between the chi-square goodness of fit statistics that are provided when using confirmatory factor analysis gives a measure of discrimination between models and allows the researcher to assess which model best fits the data. It was found that a model based on Luria and Vernon's theories involving simultaneous and successive processing, verbal and spatial abilities, and attention provided the best fit compared to the three competing models. (A number of bibliographic citations are appended.) (Author/MH)

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JOHN HATTIE

DON FITZGERALD

Centre for Behavioural Studies

University of New England

Armidale, New South Wales

AUSTRALIA

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JOHN HATTIE

DON FITZGERALD

Centre for Behavioural Studies
UNIVERSITY OF NEW ENGLAND,
Armidale, New South Wales 2351
Australia

ABSTRACT

This paper assesses four alternative theoretical models of intellectual competence using confirmatory factor analysis to account for the correlation patterns derived from Wechsler intelligence tests.

It is argued that the difference between the chi-square goodness of fit statistics that are provided when using confirmatory factor analysis give a measure of discrimination between models and allows the researcher to assess which model best fits the data.

It was found that a model based on Luria and Vernon's theories involving simultaneous and successive processing, verbal and spatial abilities, and attention provided the best fit compared to the three competing models.

This paper assesses the success of alternative theoretical models of intellectual competence in accounting for correlation patterns derived from subscales of the Wechsler intelligence test using confirmatory factor analysis to determine the goodness of fit to specified target matrices.

Confirmatory factor analysis enables tests of hypotheses which constrain the elements of a covariance or correlation matrix by expressing them as functions of a smaller number of parameters, these parameters forming a pattern that is derived from the hypotheses. It is possible to fix the parameters to some specified value, to constrain them to be equal to other values, or to free them to be estimated from the data conditional on the fixed and constrained parameters.

The first order factor analytic model is -

$$C = HSH' + U^2 \qquad (1)$$

where H is the matrix of factor-pattern loadings, S is the variance-covariance matrix, and the diagonal elements of U^2 are the unique factor coefficients.

After the maximum-likelihood estimates of the free parameters have been calculated it is possible to test the hypotheses represented by equation (1) against the alternative hypothesis that C is any positive definite matrix.

For details on maximising the log likelihood function based on the usual unbiased sample estimates of the elements of C, the reader is referred to McDonald and Swaminathan (1972), and McDonald (1978). The logarithm of the likelihood rating is N/2 times the minimum value of the function F. In large samples under the model, this is distributed as χ^2 which can be transformed (by the Wilson-Hilferty method) to a standard normal deviate (at $\alpha = 0.05$, $Z = 1.96$).

Muliak (1975) and Jöreskog (1978) have pointed out the sensitivity of χ^2 to various model assumptions such as lineratity, additivity and multinormality. Furthermore, with large samples it will almost always be possible to detect slight but unimportant departures from the model. What seems more important is the degree to which the model or reproduced covariance matrix fits the elements of the sample or observed covariance matrix.

Another method for assessing the adequacy of a model is to compare the degree of fit with that obtained by other hypothesized models. Even if it is not possible to explicate a model that cannot be rejected at conventional levels of acceptability (e.g., $\alpha = 0.05$), it is possible to assess the goodness of fit of various pre-formulated models then tentatively accepting that model which most satisfactorily fits the data. The most acceptable model is that which results in a low and unpatterned residual matrix and which is a significant improvement over competing models (determined by $\Delta \chi^2 = \chi^2_1 - \chi^2_2$ with $\Delta df = df_2 - df_1$; where subscript 1 and 2 related to competing models.)

The present paper evolved from an attempt to relate the factor structure of a comprehensive intelligence test (Wechsler, 1974) to aspects of an information processing model. The psychometric model of interest has been developed in the context of laboratory and school based research on learning and is closely related to the work of Luria (1966) and Vernon (1971). The model exhibits dimensions of simultaneous and successive information processing, spatial reasoning, verbal comprehension and attentiveness.

Information processing on intelligence tests

Carroll (1976) attempted to show how the "factors" identified in factor analytic studies of cognitive abilities can be interpreted in terms of theories and experimental work in cognitive psychology. Carroll demonstrated how the tasks on many types of psychometric tests in the cognitive domain are indeed cognitive tasks whose structure, content, and control processes can be identified. Hunt and his co-workers (Hunt, E., Frost and Lunneborg, 1973; Hunt, E., Lunneborg and Lewis, 1975; Lunneborg, 1974, 1977, Hunt, E., 1976) have sought relationships between psychometric test scores and the parameters of performances in learning and memory tasks. They have found, for example, that scores on a comprehensive verbal intelligence test were significantly related to many aspects of information processing, including speed in converting sensory data to conceptual meaning, speed in scanning data in short-term memory, retention of order information, and resistance of memory information to interfering data.

Whitely (1977) investigated the relationship between a prototypic intelligence test item - verbal analogies - and several laboratory tasks representing a series of information processing stages and concluded that the most successful analogy solver encodes and retrieves memory information about the items rapidly, but spends more time evaluating the relational quality of the information retrieval.

Yet these studies are rare compared to the common habit of trying to induce meaning from masses of correlations. This present paper is part of ongoing research investigating the adequacy of Luria's model of intellectual processing to real life behaviours (see Fitzgerald, 1973, 1975, Hunt, D., Fitzgerald and Randhawa, 1978, Green, 1977, Davidson, 1978, 1979, Davidson and Klich, 1979, Hattie, 1979a, and various M.A. and Ph.D. students at the Centre for Behavioural Studies at the University of New England). In particular, what is investigated in this paper is the adequacy of a model based on the work of Luria and Vernon as opposed to alternative models to explain the relationships between the subtests of the Wechsler intelligence scale for children (WISC).

The models

1. The two factor model

Wechsler (1949, 1974) grouped the subtests of the WISC into a verbal and a performance scale, suggesting a two factor model. Finding justification for the two factors in Wechsler's writing is difficult. The separation seemingly is based on early work by Alexander (1935) who discussed intelligence in terms of 'functional unities', one of which was a verbal factor and another was a performance factor. Wechsler (1949, 1974), discussed the two factors as a dichotomy and claimed that the dichotomy remained regardless of other ways in which the test was classified.

The verbal factor includes subscales that measure general information, general comprehension, arithmetic, similarities, vocabulary, and digit span. The performance factor includes picture completion, picture arrangement, block design, object assembly, coding, and mazes. Silverstein (1969) also argued that partialling the 12 subtests into more than two factors was trivial in terms of descriptive efficiency. Based on a principal components analysis he claimed that there was a verbal and performance component and argues that these were "the actual functional unities in intelligence test performance". Others who have argued similarly include Balinsky, (1941), Maxwell (1959), Jones (1962), Crockett, Klonoff and Bjerring (1969), Silverstein (1969, 1977), Blaha, Wallbrown and Wherry (1974), Van Hagen and Kaufman (1975), Wallbrown, Blaha, Wallbrown and Engin (1975), and Schooler, Beebe and Keopke (1978).

2. The three factor model

Three factor models have been proposed that involve a verbal, a performance and a freedom from distractibility factor. Matarazzo (1972) has argued that this third factor is replicated often enough to merit serious continued interest. Yet, it has many labels: stimulus trace, memory, attention-concentration, plasticity, holding-in-mind ability, concentration, alertness, application and the most common, freedom from distractibility. It has been found in normal and special group samples (Vance, Huelsman, and Wherry, 1976) and frequently loads on digit span, comprehension, arithmetic, and picture arrangement. The present authors found, however, that over the many studies that have reported this factor, only similarities and vocabulary have not loaded on the freedom from distractibility factor. Cohen (1952) contends that tests loading on this factor have in common the requirement of alert, undistracted attention for good performance. "In all of them, if one of the elements to be mentally manipulated by the subject does not 'register' when presented by the examiner, or is 'lost' in the course of manipulation, the subject can not make up this loss and is penalized in the scoring. Thus the naming of factor C as "Freedom from Distractibility" (Cohen, 1952, p. 363).

The three factor solution has been reported by Hammer (1950), Cohen (1952), Baumeister and Bartlett (1962), Cropley (1964), Belmont, Birch and Belmont (1967), Osborne and Tillman (1967), Kaufman (1975), Van Hagen and Kaufman (1975), Silverstein (1977), and Swerdlik and Schweitzer (1978).

3. The five factor or Cohen solution

The Cohen solution involves five factors: verbal comprehension I (information, similarities, arithmetic, comprehension, and vocabulary); perceptual organization (block design, object assembly, picture arrangement, picture completion and mazes); freedom from distractibility (digit span, mazes, picture arrangement, object assembly, and arithmetic); verbal comprehension II (comprehension, vocabulary, similarities); and a quasi-specific or undefined factor (Cohen, 1952, 1957a, 1957b, 1959).

4. The Vernon-Luria model

Vernon (1971) contends that after the removal of "g", tests tend to fall into two main groups: the verbal-numerical-education on the one hand (v:ed), and the practical-mechanical-spatial on the other hand (k:m). The v:ed factor encompasses a fairly strong unified group of abilities and the k:m results not so much from practical ability as from an aggregate of all non-symbolic capacities not usually affected by schooling.

Yet, we can go beyond the content of the tests as formulated by Vernon and include the manner in which the information is processed. Luria (1966) suggested that there are two main dimensions of the intellect which are important in cognitive tasks: a successive or sequential processing dimension and a simultaneous processing dimension. Simultaneous ability is seen as the ability to synthesise stimuli into an integrated image. That is, simultaneous ability involves the ability to reason with images of perceived spatial arrays without altering the spatial relationships that exist among the components.

Sequential processing involves an ordering of successively perceived stimuli, in that each stimuli is seen as evoking a "particular chain of successive links" which follow "each other in serial order". That is, the successive elements are not surveyable but are so integrated that each element evokes its successor.

Luria (1966) claimed, furthermore, that the directivity and selectivity of mental prodesses and the basis on which these processes are organized, is usually termed attention in psychology. By this term he implies the process responsible for picking out the essential elements for mental activity, or the process which keeps a close watch on the precise and organized course of mental activity. This conceptualization of attention seems similar to Cohen's Freedom from Distractibility factor.

Thus what we shall call, the Vernon-Luria model includes five factors: verbal-numerical-education, practical-mechanical-spatial, simultaneous processing, successive processing, and attention-freedom from distractibility.

METHOD

The WISC manual (Wechsler, 1974) presents 11 correlation matrices of the 12 subtests. There were 200 children in eleven age groups ranging in yearly intervals from 6½ to 16½. For the 2-, 3- and Cohen solutions the pattern of loadings were easily determined from the literature as described above. For the Vernon-Luria model the patterning of loadings was not so straightforward.

A description of Vernon's theories, Luria's model and the 12 WISC subtests were given to various members of the Centre for Behavioural Studies (UNE) who were asked to rank order the subtests in terms of the extent to which they related to each factor. This was done to prevent the frequent and often justified criticism that names assigned to factors have little meaning to others and can often be tautologous. The nine faculty members showed remarkable consistency as to which tests should load on the various factors.

It was predicted that digit span, vocabulary, information, picture arrangement, coding, and comprehension would load on the successive factor. Similarities, object assembly, block design, picture completion and mazes would load on the simultaneous factor. Comprehension, arithmetic, vocabulary, information, and similarities would load on the verbal-numerical-education factor. Block design, object assembly. picture completion, picture arrangement, mazes and coding would load on the practical-mechanical-spatial factor. Arithmetic, digit span, comprehension and picture arrangement would load on the attention-freedom from distractibility factor.

The 2-, 3-, Cohen and Vernon-Luria models were then tested using the 11 correlation matrices in the WISC manual via the procedure outlined at the beginning of this paper (using McDonald and Leong's (1976) COSA programme). The chi-squares, degrees of freedom, and Wilson-Hilferty Z transformations for the four hypothesized patterns are presented in Table 1.

Except for the 6½ year old sample the Vernon-Luria model is a significantly better fit than the 2- factor solution. In all cases the Vernon-Luria model is a significantly better fit than the 3- factor solution and the Vernon-Luria model is a significantly better fit for all but four age groups than the Cohen solution (see Table 2).

The factor loadings averaged across the 11 samples are presented in Table 3.

Table 1 near here

Table 2 near here

Table 3 near here

TABLE 1

Chi-squares, degrees of freedom, and Z-transformations for testing the goodness of fit of the four hypotheses related to the underlying structure of the WISC data.

	2 factor (df = 53)		3 factor (df = 51)		Cohen 5 factor (df = 36)		Vernon-Luria 5 factor (df = 30)	
Age Group	χ^2	Z	χ^2	Z	χ^2	Z	χ^2	Z
6½	64.07	1.07	69.34	1.73	37.80	0.50	33.18	0.47
7½	84.27	2.74	79.41	2.55	46.63	1.23	36.47	0.86
8½	105.38	4.27	71.35	1.90	45.14	1.08	27.27	0.30
9½	105.78	4.30	97.78	3.94	62.87	2.79	43.70	1.67
10½	94.88	3.51	74.50	2.16	43.17	0.87	36.42	0.85
11½	113.82	4.84	100.84	4.15	62.86	2.79	39.09	1.16
12½	100.56	3.93	73.64	2.08	63.55	2.85	35.47	0.74
13½	117.67	5.09	102.04	4.24	68.17	3.25	54.43	2.75
14½	110.27	4.60	94.35	3.69	66.02	3.07	56.13	2.91
15½	114.36	4.88	98.04	3.95	64.85	2.96	49.65	2.28
16½	113.63	4.83	81.12	2.69	59.64	2.50	40.65	1.27

TABLE 2

Differences in χ^2 and significance level between the Vernon-Luria model and the 2-, 3-, and Cohen-solutions.

Age Group	Vernon-Luria vs 2-factor (df=23) $\Delta\chi^2$	p	Vernon-Luria vs 3-factor (df=21) $\Delta\chi^2$	p	Vernon-Luria vs Cohen-solution (df=6) $\Delta\chi^2$	p
6½	30.89	.87	36.16	.98	4.62	.41
7½	47.80	.99	42.94	.99	10.16	.88
8½	78.11	.99	44.08	.99	17.87	.99
9½	62.08	.99	54.08	.99	19.17	.99
10½	58.46	.99	38.08	.99	6.75	.66
11½	74.73	.99	61.75	.99	23.77	.99
12½	65.09	.99	38.17	.98	28.08	.99
13½	63.24	.99	47.61	.99	13.74	.97
14½	54.14	.99	38.22	.99	9.89	.87
15½	64.71	.99	48.39	.99	15.20	.98
16½	72.98	.99	40.47	.99	18.99	.99

TABLE 3

The average factor loadings, correlations between factor and uniquenesses for the 5 factor Vernon-Luria model.

	1 Successive	2 Simultaneous	3 Verbal	4 Spatial	5 Attention	U[2]
Information	0.402	0	.497	0	0	.132
Similarities	0	-.636	.244	0	0	.070
Arithmetic	0	0	.599	0	.602	.217
Vocabulary	.690	0	.369	0	0	.058
Comprehension	.186	0	.704	0	.064	.190
Digit Span	.374	0	0	0	.495	.194
Picture Completion	0	-.286	0	.563	0	.316
Picture Arrangement	.294	0	0	.544	-.303	394
Block Design	0	-.159	0	.826	0	.100
Object assembly	0	-.212	0	.702	0	.212
Coding B	.265	0	0	.249	0	.625
Mazes	0	.011	0	.529	0	.455

Successive	1.000				
Simultaneous	-.412	1.000			
Verbal	.458	-.429	1.000		
Spatial	.481	-.213	.461	1.000	
Attention	.467	.111	-.102	.333	1.000

The stability of the Vernon-Luria model over the 11 age groups was assessed by calculating coefficients of congruence between all factors. The mean coefficient between non-matching factors was 0.036 and between matching factors was 0.712. The mean congruence coefficient for the successive factor was 0.745, for the simultaneous factor was 0.518, for the verbal factor was 0.673, for the spatial factor was 0.951, and for the attention-freedom from distractibility factor was 0.674. This evidence indicates considerable stability of the factors over all age groups.

Discussion

The usefulness of testing the goodness of fit of various models of intellectual processing using confirmatory factor analyses has been demonstrated. Underlying the Wechsler intelligence scale for children there seems to be two factors relating to the way children process the information (simultaneous and successive processing), two factors relating to the content of the tests (verbal and performance) and an attention or freedom from distractibility factor. The two factor, three factor, and the Cohen solutions do not provide as good a fit and should be rejected in favour of the Vernon-Luria model.

It is suggested that other models could be assessed using the methods described in this paper and also second-or higher-order models could also be incorporated. Certainly we do not contend that the Vernon-Luria model provides the 'best' fit, merely that it should be accepted until a more satisfactory model is proposed. It would seem that confirmatory factor analysis is a useful method to discriminate between the goodness of fit of various educational and psychological models (see Hattie, 1979b for another example using the Personal Orientation Inventory). The use of confirmatory factor analysis in this manner should be a step forward in uniting what Cronbach (1975) has critically termed the two disciplines in scientific psychology, one the psychometric, one the experimental.

Studies using the Vernon and particularly the Luria model are suggesting that models of information processing rather than traditional models of intellectual competence may be a more beneficial method of conceptualizing intelligence (see Fitzgerald, 1973; Biggs, 1978).

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