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AN EXPLORATORY FACTOR ANALYSIS OF FIVE NEW COGNITIVE TESTS FOR USE ON AFRICAN MINEWORKERS

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This study was undertaken to examine the factor structure of five new cognitive tests for Africans. In surveying the literature previous factor analytical studies on cognitive tests for Africans are critically appraised. The shortcomings of these studies are indicated and some of the results re-analysed. Ten cognitive tests were administered to a sample of 90 African mine recruits. The reliabilities of the tests were calculated, the tests intercorrelated and the resultant matrix subjected to a principal factor analysis. Contrary to other studies of this kind, the factor analysis yielded a clear two-factor structure. The possibility of extending the factor space to incorporate two further group factors is discussed. It is shown that if matrices of factor loadings are rotated to simple structure the necessity to resort to blanket terms in interpreting factors becomes redundant. It is concluded that more new and diverse tests are necessary if the intellect of Africans is to be studied properly. The five new tests are regarded as a useful addition to available tests for Africans at this level.

From two recent literature surveys (6, 2) it is clear that two main approaches have been followed in the construction of cognitive tests for Africans. The first, and most popular, approach has been to accept the basic rationales of existing overseas tests and to modify them in minor ways (19, 12, 1). The second, and perhaps more fruitful, approach has been to develop novel techniques, utilizing concepts and materials familiar to Africans, for measuring their cognitive functions (17, 14, 5). Both kinds of tests have been used in applied studies such as selection and classification as well as in fundamental studies on the structure of African intellect.

The practice of adapting overseas tests without first establishing the difficulty values and discrimination indices of the items for African samples has led to the creation of tests of doubtful reliability and validity. In contrast, those tests which have been developed de novo have withstood critical scientific scrutiny.

Fundamental studies, unlike studies of a purely applied nature, held promise of extending our knowledge of the structure of African intellect. However, an examination of basic investigations published to date, reveals that just the opposite has been achieved. Typical of these studies was the finding of unitary factors. This was largely because they were planned at a stage when there were insufficient appropriate tests for exploring the cognitive domain of Africans. In fact, the factor structures obtained were more descriptive of the status of test development at that particular moment in time than of the structure of intellect. It is the contention of the authors that Spearman's one-factor structures arose because of a similar shortcoming. Furthermore, adherence to the British factor analytical school of thought has resulted in the use of such blanket descriptions as g and general adaptability. This narrow view of the structure of intellect has stifled the exploration of African intellect in a wider context and is one of the main reasons why very few new tests have been produced.

The first factor analytical study, to the authors' knowledge, of cognitive and psychomotor tests designed for

use on Africans was that of MacDonald (11). The primary purpose of his study was to condense a battery of thirteen tests into the smallest yet most effective battery for selection purposes. MacDonald's investigation was pioneering in that the tests he used were first carefully item analysed and then those of doubtful reliability were discarded. A total sample of 1,855 African recruits was tested. However, the matrix of intercorrelations was based on unequal sample sizes as the records were incomplete. Since most of the correlations were calculated on 1,000 or more cases a good measure of stability was introduced into his analysis.

A centroid factor analysis was performed on the matrix of intercorrelations which yielded a three-factor structure. An interpretation of these factors is not offered, probably because the matrix was not rotated to simple structure. A striking feature of the study is that all the tests have large specificities.[1] The total variance of a test can be divided into three components viz. common variance, specific variance and error variance. The reliable variance of a test comprises common variance plus specific variance. Specific variance plus error variance

1 The estimates of specificities as reported by MacDonald are in error. The values need to be squared to be correct. It should be noted that the term specificity as used by MacDonald is in fact Thurstone's term uniqueness.

equals unique variance. A large specific variance means that only a small proportion of the reliable variance of a test is shared by other tests. In order to exhaust the specific variances of the tests in MacDonald's battery, several more tests need to be constructed to recover the specific variance in the form of common variance. A larger and more diversified battery of tests might yield many more than three factors. This extended battery could supply the conceptual framework within which new tests might be constructed.

MacDonald validated his tests against a criterion of proficiency and obtained a multiple correlation of .43. The criticism of unequal sample sizes also applies to this aspect of his study.

In 1946 work was started by Biesheuvel, Hudson and others on the construction of a battery of tests for the selection and classification of African mineworkers. By 1949 the tests were operational in the mining industry. These tests constitute what is known as the General Adaptability Battery. The rationales underlying the tests are clearly described by Biesheuvel in a paper published in 1952 (3). In a subsequent paper (4) he presented the results of this investigation and included information on the reliability and validity of the tests. This was followed up by Hudson (9) who validated the battery against an occupational criterion. Although not explicitly stated in any of the studies mentioned above MacDonald's work seems to have had some determining influence on the choice of the tests con-

stituting the battery. The four tests with the highest loadings on the first principal axis in MacDonald's study were: Mechanical Assembly (Form A), Formboard (Circular Insets), Block Design and Cube Construction.

Vernon (20) applied the identical battery to that of MacDonald, to a sample of African recruits.[2] His records were also incomplete inasmuch as the number of subjects completing each test varied between 308 and 631. He also extracted three factors but decided to discard the third one as it failed to yield a logical grouping of the tests. His first two factors agree very closely with those obtained by MacDonald. Vernon interprets the first factor as general adaptability. He feels that it is unrelated to g, in the sense of educing relations, since it loads highly on the simple formboards and dexterity tests. The second factor, according to Vernon, is a bipolar factor which divides the tests into the primarily cognitive and the primarily manipulative and physical. He maintains that the cognitive factor is quite close to British g while the opposite pole is a mixture of manual dexterity and physical factors. If Vernon's matrix of factor loadings is rotated to simple structure the picture becomes clearer and the

2 It came as a surprise to note that Vernon did not mention MacDonald in his book notwithstanding the fact that he used the same battery of tests as MacDonald.

necessity to resort to a dubious blanket term such as general adaptability can be dispensed with.

	Tests	I	II		A	B		X	Y
1.	Arithmetic	.57	.34		.6770	.7359		.136	.649
2.	Progressive Matrices	.66	.29	•	-.7359	.6770	=	.233	.682
3.	Fourth Corner Test	.66	.23			Λ		.278	.641
4.	Block Design	.68	.18					.328	.622
5.	Cube Construction	.68	.08					.401	.555
6.	Mechanical Comprehension	.27	.07					.131	.246
7.	Formboard (circular insets)	.69	.02					.452	.521
8.	Formboard (square insets)	.56	-.03					.401	.392
9.	Mechanical Assembly	.77	-.07					.573	.519
10.	Screwboard Dexterity	.64	-.20					.580	.336
11.	Reversible Blocks Dexterity	.56	-.21					.534	.270
12.	Pegboard Dexterity	.41	-.30					.498	.099
13.	Agility	.40	-.42					.580	.010
			F					V	

The communalities (h^2) and uniquenesses ($u^2 = 1 - h^2$) of the tests are as follows:

Test	h^2	u^2
1	.440	.560
2	.519	.481
3	.488	.512
4	.494	.506
5	.469	.531
6	.077	.923
7	.476	.524
8	.314	.686
9	.597	.403
10	.449	.551
11	.358	.642
12	.258	.742
13	.336	.664

After rotation the following tests have the highest loadings on the first factor: Progressive Matrices, Arithmetic, Fourth Corner, Block Design, Cube Construction, Formboard (circular insets) and Mechanical Assembly. All of these tests involve the eduction of relations to a greater or lesser extent. The second factor is characterised by high loadings on: Agility, Screwboard Dexterity, Mechanical Assembly, Reversible Blocks Dexterity, Pegboard Dexterity, Formboard (circular insets) and Formbaord (square insets). These tests seem to describe a dimension of dexterity.

Murray (13) applied a battery of 19 performance tests to a sample of 119 African industrial workers. He

subjected the matrix of intercorrelations of the various tests to a factor analysis using Burt's simple summation technique. Three factors were extracted and the significance of the factor loadings was tested by means of the chi-squared test of Burt and Banks. Only one factor was considered significant using this "rule of thumb decision" procedure. After an extensive deliberation on the adequacy of the test battery and the possible reasons for obtaining a one-factor structure Murray concludes: "..... that so far as the African is concerned the simplicity of the factor structure is determined by a simplicity of mental structure (p.63)" and not by the inadequacy of the battery used by him (cf. p.59).

Despite the fact that Murray's battery included virtually all the tests available for Africans at that time he disregarded the basic assumptions underlying factor analytical design. To determine a hypothesized dimension adequately, three or more tests loading on that dimension are required. If only two tests load on a particular dimension it is impossible to obtain unique estimates of communality. By definition a common factor cannot exist if only one test loads on the hypothesized dimension. It is also desirable that the tests included in a factor analytical design be factorially as simple as possible.

A proper test for estimating the number of factors in Murray's study might have yielded more than one common factor. For a more precise estimate of the number of factors the Maximum Determinant Model for factoring the

battery of tests, followed by a series of Maximum Likelihood Ratio Tests, is recommended. An inspection of his matrices of factor loadings reveals large specificities for all the tests which lends support to the observation that his battery of tests is ill-determined. The same criticism regarding the use of the term general adaptability as was levelled at Vernon applies in this case and deserves no further comment.

Schepers, Hector and Grant (15) applied a battery of six cognitive tests to 246 African workers in secondary industry. An analysis of the content of these tests would have lead one to postulate at least a two-factor structure. However, when the matrix of intercorrelations was factored only one factor proved significant according to Kaiser's criterion. A striking feature of this one-factor structure was that the communalities were quite high, indicating in turn low specificities. This is in contrast to the findings of MacDonald and Murray. The fact that a single factor was involved and that the specificities were low seems to indicate that the tests measure a single factor in fairly pure form. The six tests in the battery all involve the eduction of relationships. One may therefore safely assume that they define a group factor of general intelligence. This does not imply that the intellect of Africans is simple in structure, as Murray would contend, but that the battery under consideration yields a well-determined factor of inductive reasoning similar in structure to that defined by Thurstone (18).

From the foregoing review it should be clear that

fundamental studies on the structure of African intellect, if undertaken prematurely, can do more harm than good to the development of tests of the primary mental ability kind for Africans.

In the present study an attempt will be made to examine the factor structure of five new tests in conjunction with five older tests in a factor test battery. The possibility of extending the factor space to incorporate two new group factors will be indicated.

Method

Sample

A sample of 90 male African mine recruits was obtained from Durban Roodepoort Deep. The sample was typical of mine recruits in that it was culturally heterogeneous. The mean number of years of formal schooling was 1.47 years (S.D. = 2.34). Approximately 70 percent of the sample had never been to school and the remainder had only a smattering of formal schooling. The mean age of the sample was 31.16 years (S.D. = 9.49).

Description of New Tests

(a) Circles Test

There are 19 items in the Circles Test; three of which are practice items. Each item has a pattern, four pieces to make up this pattern and a number of distractor pieces. Items 1 to 5 each have two distractors, while the remaining items each have four distractors.

The pattern and loose pieces are placed in front of the testee. He is required to sort out four pieces and assemble them to reproduce the given pattern. A time limit of one minute is allowed for the three practice items and two minutes each are allowed for the remaining items.

(b) Form Perception Test

The Form Perception Test is a paper version of a typical formboard. The pieces are in the form of paper cut-outs blackened on the one side and gummed on the other. The smallest piece is a right-angled isosceles triangle. The next piece is a compound of two of the smaller pieces. The third piece is compounded of three of the smaller pieces to form a trapezium. The formboard outlines are printed on the pages of a booklet and are all symmetrical in shape. The test contains one practice item and nine test items.

The testees are provided with ten sets of the three shapes and the booklet containing the outlines. The subject is required to position the three pieces within the outline and when he is satisfied that they fit, he has to stick them in position. Thus a permanent record of his solution is obtained. A time limit of three minutes is imposed upon each item. The test is scored by allocating one mark for each piece correctly placed.

(c) Fret Repetition

The Fret Repetition Test is a booklet containing two practice items and ten test items. Each item is printed on a separate page. At the top of the page is a configuration of dots joined by means of continuous straight lines to form a pattern silimar to those found on Greek vases. At the bottom of the page only the dots are presented. The testee is required to join these dots by means of straight lines to reproduce the model pattern. No time limit is imposed on the test but it has been found that testees require only a minute or two to reproduce the patterns. One mark is credited for each pattern correctly reproduced.

(d) Fret Continuation Test

The Fret Continuation Test is a booklet containing two practice items and twelve test items. Like the

Fret Repetition Test each item is printed on a separate page. It also has a configuration of dots joined by means of continuous straight lines at the top of the page but an incomplete reproduction of the model pattern is presented at the bottom of the page. The patterns of this test are longer than those of the Fret Repetition Test and are, on the whole, more difficult. The testeee is required to trace the given part of the pattern with a pencil and then continue it on his own until he has completed it. Again, no time limit is imposed. Testees generally require two to three minutes for each item. One mark is credited for each pattern correctly completed.

(e) Form Series Test

The Form Series Test contains four practice items and eighteen test items. The items are printed on a sheet of durable paper which is wrapped around a plywood board. The sheet of paper is affixed to the board by means of double-coated masking tape. Each item is a sequence of symbols; each symbol being a compound of a particular size, colour and shape. Only part of a sequence is presented in each item and the testee is required to continue it by affixing two plastic forms, selected from a tray, to the strip of double-coated masking tape. The test items increase in order of difficulty as the test progresses. The items selected for this version of the test are confined to the "in phase" type of item described

by Grant (8). In marking the items of the test, credit is given only if both answer forms are correct in all respects i.e. the shape, colour and size all have to be correct.

Test Administration

All the tests mentioned above were administered on the bais of a procedure advocated by Schwarz (16). Visual aids and demonstrations were incorporated and emphasis was placed on the practice items so that over-learning could take place. At the same time, feedback on the comprehension of the subjects was obtained. Oral supplements in Fanagalo were also incorporated into the procedure. This procedure has the advantage of getting the testees to participate actively from the start. An attempt was made to keep the administration as standard as possible. The same African tester, who was thoroughly trained, administered the tests throughout all the testing sessions. The test patter was presented in standard form during each testing session.

The General Adaptability Battery

A description of the General Adaptability Battery is considered unnecessary as it is well known and has been described on numerous occasions in the literature.(4, 9, 8). The battery was administered in the usual way i.e. by means of a silent 16 mm. ciné film which gives all the instructions

and demonstrations in pictorial form and through medium of mime. The Kohs Blocks Test, however, was administered in the same way as the battery of new tests.

Procedure

The sample was tested at the aptitude testing centre of the mine mentioned above. The battery of ten tests was administered to groups of ten subjects at a time. The General Adaptability Battery was administered first. On completing the battery the testees were allowed a break. They were then tested on the Circles Test and the Form Perception Test and allowed another break. Finally they were tested on the Fret Repetition Test, the Fret Continuation Test and the Form Series Test.

Statistical Analysis and Results

(i) Means, standard deviations, coefficients of skewness and kurtosis

The means, standard deviations, coefficients of skewness and kurtosis of the sample on the tests are shown in Table 1.

Table I

Means, standard deviations, coefficients of skewness and kurtosis

Tests	Mean	S.D.	Skewness	Kurtosis
Kohs	18.81	9.98	0.88	0.42
Circles	48.90	13.88	-0.62	-0.13
Form Perception	18.23	6.60	-0.41	-0.74
Fret Repetition	6.77	2.79	-0.84	-0.39
Fret Continuation	3.50	3.24	0.94	0.16
Form Series	6.58	4.75	0.57	-0.70
Sorting I	76.56	35.14	0.17	-0.50
Sorting II	68.28	39.05	0.45	-0.56
Cube	16.94	13.70	0.91	0.05
Tripod	37.50	15.91	-0.60	0.03

(ii) Estimation of Reliabilities

In a study conducted by Lourens (10) it was found that the Circles Test is multi-dimensional. It was therefore, not possible for him to estimate the reliability of the test with the Kuder-Richardson formula 20. He decided instead to use Kuder-Richardson formula 3, taking as estimates of the item reliabilities the communalities of the items obtained from the factor analysis of the test. The reliability coefficient he calculated was .92.

As the weights used in scoring both the Form Perception Test and the Kohs Blocks Test were other than 0 and 1 it was necessary to utilize Ferguson's extension of Kuder-Richardson's formula 20 (7) to calculate their reliabilities. The reliabilities of the Form Perception Test and the Kohs Blocks Test were .80 and .70 respectively.

Kuder-Richardson formula 20 was used to calculate the reliabilities of the Fret Repetition Test, the Fret Continuation and Form Series tests. The reliabilities were .83, .87 and .90 respectively.

The reliabilities of the sub-tests of the General Adaptability as reported by Biesheuvel (4) were as follows: Sorting Test I .88, Sorting Test II .91, Cube Construction Test .79, and Tripod Assembly Test .83.

(iii) Factor Analysis

The battery of ten tests were intercorrelated using Pearson's product-moment correlation technique. The matrix of intercorrelations appears in Table 2.

Table 2

Matrix of intercorrelations

Tests	1	2	3	4	5	6	7	8	9	10
1. Kohs	1.00	.63	.32	.61	.60	.33	.32	.42	.52	.38
2. Circles	.63	1.00	.46	.64	.62	.43	.41	.51	.47	.37
3. Form Perception	.32	.46	1.00	.23	.28	.25	.35	.41	.30	.39
4. Fret Repetition	.61	.64	.23	1.00	.61	.41	.27	.46	.40	.35
5. Fret Continuation	.60	.62	.28	.61	1.00	.29	.38	.54	.29	.41
6. Form Series	.33	.43	.25	.41	.29	1.00	.24	.31	.34	.21
7. Sorting I	.32	.41	.35	.27	.38	.24	1.00	.73	.52	.48
8. Sorting II	.42	.51	.41	.46	.54	.31	.73	1.00	.51	.43
9. Cube	.52	.47	.30	.40	.29	.34	.52	.51	1.00	.49
10. Tripod	.38	.37	.39	.35	.41	.21	.48	.43	.49	1.00

The matrix of intercorrelations was subjected to a principal factor analysis. The initial communality estimates were taken as zero and the number of factors to be iterated on was estimated by Kaiser's criterion. Iteration was continued until the communalities converged to a tolerance of .005. Only two factors appeared to be significant according to Kaiser's decision rule. The matrix of residuals appears in Table 3.

Table 3

Matrix of residuals

	1	2	3	4	5	6	7	8	9	10
1	.39	-.01	-.01	-.01	.03	-.04	-.02	-.04	.09	.01
2	-.01	.32	.10	-.02	.01	.04	.01	-.03	-.01	-.05
3	-.01	.10	.75	-.08	-.04	.04	-.04	.00	-.03	.08
4	-.01	-.02	-.08	.35	.03	.03	.00	.04	-.01	.00
5	.03	.01	-.04	.03	.46	.06	.02	.07	-.13	.03
6	-.04	.04	.04	.03	-.06	.78	-.01	.00	.05	-.05
7	-.02	.01	-.04	.00	.02	-.01	.20	.04	-.01	-.02
8	-.04	-.03	.00	.04	.07	.00	.04	.34	.02	-.07
9	.09	-.01	-.03	-.01	-.13	.05	-.01	-.02	.55	.08
10	.01	-.05	.08	.00	.03	-.05	-.02	-.07	.08	.63

An inspection of this matrix of residuals indicates that two factors were sufficient to account for all the common variance of the tests.

The matrix of orthogonal factor loadings appears in Table 4. A plot of the two factors against one another

Table 4

Matrix of orthogonal factor loadings

Tests	I	II
Kohs	.73	-.28
Circles	.79	-.24
Form Perception	.49	.11
Fret Repetition	.71	-.38
Fret Continuation	.70	-.22
Form Series	.46	-.11
Sorting I	.68	.58
Sorting II	.76	.29
Cube	.65	.15
Tripod	.58	.17

indicated that a rotation of -38 degrees of the original axes would result in a fairly clear structure which is positive manifold. The rotated factor matrix appears in Table 5.

Table 5

Rotated factor matrix, communalities, uniquenesses and specificities

Tests	A	B	h^2	u^2	s^2
Kohs	.75	.23	.61	.39	.09
Circles	.77	.30	.68	.32	.24
Form Perception	.32	.39	.25	.75	.55
Fret Repetition	.79	.14	.65	.35	.18
Fret Continuation	.69	.26	.54	.46	.33
Form Series	.43	.20	.22	.78	.68
Sorting I	.18	.88	.80	.20	.08
Sorting II	.42	.70	.66	.34	.25
Cube	.42	.52	.45	.55	.34
Tripod	.35	.49	.37	.63	.46

The uniquenesses and specificities of the tests were calculated by means of the following formulae:

$$u^2 = 1 - h^2$$

$$s^2 = r_{tt} - h^2$$

where:

u^2 = uniqueness

s^2 = specificity

h^2 = communality

r_{tt} = reliability

The obtained coefficients are also listed in Table 5.

Discussion

Contrary to popular belief the goal of good test construction is not to produce normal distributions but rather platykurtic distributions. In other words what is required is to spread out the subjects as widely as possible on the score continuum. The truth of this statement is clarified when one inspects Kuder Richardson formula 20, presented in the following form:

$$KR_{20} = \left[1 - \frac{k\Sigma S_g^2 - S_x^2}{(k-1)\, S_x^2} \right]$$

where k = number of items

S_g^2 = item variance

S_x^2 = test variance

As the test variance increases so the reliability of the test also increases. The reliabilities of all the tests in the factor battery are of an acceptable magnitude. The lowest is in fact Kohs Blocks with a reliability of .70. Thus the tests used are sensitive enough to reflect small individual differences in a reliable way.

An inspection of Table 1 will show that none of the tests are skewed in an exaggerated way, indicating therefore that the tests were, on the whole, of an appropriate level of difficulty. It is interesting to note that all the new tests, with the exception of the Fret Continuation Test, are platykurtic. The Fret Continuation

Test tends however towards normality. The remarks made above relate to the raw score distributions of the tests. For interpretive purposes these raw scores would naturally be transformed into normalised standard scores.

An inspection of the matrix of intercorrelations (Table 2) shows that all the tests correlate positively with one another. The lowest correlation is .23 and the highest .73. A partitioning of the matrix into the new and old batteries reveals that the average correlation within batteries is higher than the average correlation between batteries. This suggests at least a two factor structure.

An inspection of the matrix of residuals (Table 3) after having extracted two factors shows that the coefficients all approach zero thus confirming the Kaiser criterion that two factors are adequate to account for all the common variance of the tests.

The rotated factor matrix (Table 5) reveals that the first dimension is best defined by the following tests: Fret Repetition, Circles, Kohs Blocks, Fret Continuation, Form Series, Sorting II and Cube Construction. All these tests involve the reproduction of given patterns and both analysis and synthesis are required in obtaining a solution. This dimension is similar in content to that identified in the study conducted by Schepers, Hector and Grant. The second dimension is best defined by: Sorting I, Sorting II, Cube Construction, Tripod and Form Perception. All the tests involve the sorting of objects under speeded

conditions. This dimension is therefore interpreted as speed of perception.

An inspection of the communalities relative to the reliabilities of the tests (Table 5) reveals that both the Form Series Test and the Form Perception Test have a large proportion of specific variance still unaccounted for. The present battery needs to be extended to overdetermine the dimensions defined by these two tests. An extension of this kind would probably make a four factor structure possible.

Conclusion

All the new tests were constructed de novo and utilized concepts with which the sample was able to cope. The tests all have high reliabilities and spread out the subjects in such a way that small individual differences are reflected. It is concluded that these tests are a useful addition to the available tests for Africans at this level.

The factor analysis carried out on the battery of ten tests yielded a clear two-factor structure. If the battery were to be extended to overdetermine the dimensions defined by the Form Series Test and the Form Perception Test the rank of the matrix would be increased from two to four.

This investigation has shown that to study the cognitive abilities of Africans properly more new and

diverse tests are necessary. If rotations to simple structure are performed on the matrices of factor loadings the interpretation of factors becomes clearer and the necessity to resort to concepts such as g and general adaptability disappears. The structure of the intellect of Africans is thus not as simple as other investigators would have us believe.

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