

Simultaneous and Successive Processing:

a Reanalysis of Kirby and Das's Data

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A resurgence of interest in the skills and abilities that comprise intelligent performance has been noted by Kilian (1978). A promising approach to the study of individual differences in cognition is that of information processing. However, Carroll (1978), in surveying literature on this area, suggests that psychometric procedures have often been misused when information processing constructs have been used to study intelligence. One information processing approach to the psychometric assessment of cognitive abilities has been proposed by Das, Kirby and Jarman (1975). Their model uses the constructs of simultaneous and successive processing and has been compared to the more traditional model of primary mental abilities by Kirby and Das (1978).

Simultaneous processing is assessed by Raven's Matrices, a figure copying task and a memory for designs test; successive processing by serial recall of words, a visual short term memory test and digit span, while a third construct, speed, is represented by speed tests of reading and colour naming.

Kirby and Das (1978) examined the relationship between these eight measures of information processing and six tests representative of primary mental abilities (Thurstone, 1938). Their analysis comprised separate principal components analysis of the simultaneous and successive (SS) battery and the primary mental abilities (PMA) battery. Correlations between SS factors and PMA tests, SS tests and PMA factors and SS factors with PMA factors were examined.

Some further analysis of the data presented in the Kirby and Das study (1978) may be justified by reference to the lack of analytic power in the bivariate correlations used to map relationships between the SS and PMA domains, given that the study attempted to relate the two batteries, "not to evaluate whether one is in any sense better" (Kirby and Das, 1978, p. 60). A further criticism is the use of principal components analysis instead of a common factor procedure. As well, exploration of the data with alternative multivariate procedures should help to confirm the construct validity and the empirical validity of the SS tests in relation to the PMA battery (See Sternberg, Note 1).

It should be noted that principal components analysis mixes up common, specific and error variance (Rummel, 1970, p. 112ff) unlike classical factor analysis which assumes that the variables are affected by various influences, and that these may be shared by other variables. Additionally, Carroll (1978) suggests that principal components analysis tends to yield factor loadings that are considerably inflated over other types of factor analyses. He believes this can lead to "over-generous factor interpretations" (p.95).

Pursuing the relationship between the factors of both batteries and the factors and tests of each, Kirby and Das use a bivariate correlational method, which is rather restricted as it is possible only to evaluate the variation in one variable in its relationship to the variation in another. The

relationship between the two batteries is limited as the effects of variables not in the analysis are not being accounted for and hence are unknown. The relatedness of the batteries as a whole, therefore, cannot be ascertained.

Canonical correlation appears to be a useful method for viewing the relationship between two sets of variables (Amick and Walberg, 1975). With such a method, a linear combination of one set of variables is maximally correlated with a linear combination of the other set. The effect therefore of each variable in the set is represented and hence any reanalysis of two test batteries could benefit from such a technique. However, Cooley and Lohnes (1971) and Van Den Wollenberg (1977) identify some limitations of canonical correlation in that it gives no information about the explained variance extracted from the two sets of variables.

Van Den Wollenberg (1977, p.208) summarizes the interpretive difficulties of the analysis by stating "a high correlation says nothing about the communality of two sets of variables.... it is as such an analytical tool which is hard to interpret". In an effort to provide more information about sets of variables while avoiding the interpretation of difficulties of canonical correlation, Stewart and Love (1968) introduced the notion of a redundancy index, an analytical procedure which produces a measure of the shared variance between two sets of variables. Such a measure when used in conjunction with canonical correlation thus appears necessary in the reanalysis of the present data.

#### Method

Correlation matrices presented by Kirby and Das (1978) were analysed by classical factor analysis and canonical correlation using SPSS package programs (Nie, Hull, Jenkins, Steinbrenner and Bent, 1975). A redundancy analysis was also performed, using the REDANAL program (Thissen and Van Den Wollenberg, 1975).

For specific details regarding subjects, tests and procedures, reference should be made to Kirby and Das (1978, pp. 59-61).

#### Results

##### Factor Analyses

The correlation matrix for all 14 variables in the analysis was submitted to a classical factor analysis (SPSS program PA2). The four factors with eigenvalues greater than one were rotated to equimax criteria (Table 1.)

Results were similar to those obtained in the principal components analysis of Das and Kirby (1978). Factor one again was found to be most complex as tests of simultaneous processing, (Raven's Matrices and Memory for Designs), along with PMA tests (figure grouping and word grouping) and spatial relations load on it. Factor two is clearly processing tests and tests of associative memory in the PMA battery. Factor four is again interpreted as a speed factor.

A similar equimax rotated factor analysis was performed for the eight SS variables (Table 2.) Factor one is clearly simultaneous processing whilst factor two is that of successive processing. Factor three is a speed factor. These results are also similar to the principal components of Kirby and Das. However in the present analysis a clearer distinction between factors is observable. Serial recall is found not to load as heavily on simultaneous processing but rather exhibits a similar loading to digit span on the successive factor.

Principal factor analysis with equimax rotation of the six PMA variables gave results noted in Table 3. Factor one combines high loadings of reasoning tests (figure grouping, word grouping), along

Table 1.

Factor Analysis of Eight Simultaneous-Successive Tests and Six Primary Mental Abilities Tests (Equimax Rotation).

Variables	Equimax Factors				
	1	2	3	4	5
Raven's matrices	.6186	.1775	.2549	-.3549	.6870
Figure copying	.2461	.2094	.5118	-.0962	.3757
Memory for designs	.4349	.0200	.4946	.0387	.4357
Serial recall	.2889	.5314	.3038	.1681	.4865
Visual short-term memory	.0851	.8631	.1928	.0275	.7902
Digit span	.0417	.5113	.1398	.1231	.2978
Word reading	-.0133	.3894	.0199	.6068	.5205
Colour naming	.1270	-.0231	.0971	.7220	.5473
Figure grouping	.5246	.0355	.2015	.1074	.3286
Word grouping	.4865	.2442	.0684	.2968	.3891
First-last names	.2504	.1921	.5249	.1737	.4052
Word-number	.0551	.2775	.5983	.1589	.4633
Spatial relations	.6637	.1330	.2656	.1159	.5421
Card rotations	.6317	.1380	.1799	.2321	.5043

with spatial relations. Factor two is clearly a memory factor as tests of first-last names and number load on it. The emergency of only two factors with eigenvalues greater than one is similar to the results of Kirby and Das. Extraction of a third factor was not done in the present analysis. A review of factors three, four and five before rotation indicated eigenvalues of similar magnitude and hence to include one additional factor for rotation and ignore the others seemed inappropriate.

Table 2

Factor Analysis of Simultaneous-Successive Battery (Equimax Rotation)

Variable	Unrotated factors			Equimax factors			h <sup>2</sup>
	1	2	3	Sim	Succ	Speed	
Raven's matrices	.4381	-.5428	.0266	.6267	.1839	-.2464	.4872
Figure copying	.5078	-.2740	.1122	.5340	.2448	.0222	.3455
Money for designs	.4979	-.3803	.4466	.7545	.0037	.1506	.5920
Serial recall	.6850	-.0003	-.0210	.3993	.5236	.1900	.4696
Visual short-term memory	.7759	.1247	-.4510	.1700	.8890	.0397	.8208
Digit span	.4669	.1403	-.2017	.0927	.5066	.1145	.2784
Word reading	.4515	.6454	.1207	-.0930	.4109	.6763	.6349
Colour naming	.2398	.4705	.4711	.0592	-.0064	.7052	.5008

Table 3

## Factor Analysis of Primary Mental Abilities Battery (Equimax Rotation)

Variable	Unrotated factors		Equimax factors		h <sup>2</sup>
	1	2	Reasoning Spatial	Memory	
Figure grouping	.5656	-.1283	.5489	.1872	.3364
Word grouping	.5320	-.0729	.4913	.2168	.2884
First-last names	.6239	.5235	.2570	.7728	.6633
Word number	.3707	.3747	.1193	.5134	.2778
Spatial relations	.7089	-.2508	.7352	.1579	.5654
Card rotations	.7026	-.2509	.7299	.1546	.5566

Canonical Correlations

The SPSS program was used to relate the two sets of variables, i.e. SS and PMA. Tables 4 and 5 present the results of the analysis. In Table 4 the magnitude of the eigenvalues indicates the proportion of variance shared by the pair of canonical variates. Table 5 provides specific information about the relative contribution of the original variables to the canonical variates. Only one canonical variate in each analysis was found to be statistically significant ( $p < .05$ ).

Examination of the canonical analyses indicates that the canonical correlation of greatest magnitude (.6981) exists between a linear combination of the SS tests and a linear combination of the PMA factors. In this canonical correlation the simultaneous processing tests of Raven's Matrices and memory for designs along with the successive processing test of serial recall load most heavily. The weightings of the PMA factors, with the exception of serial recall, over the successive tests and factors in the canonical correlations with the PMA factors and tests is a feature of all the canonical correlations.

Table 4

## Canonical Correlation of the Primary Mental Abilities with the Simultaneous-Successive Factors

Number	Eigenvalue	Canonical Correlation	Wilk's Lambda	Chi-square	D.F.	Significance
PMA Tests v. SS factors						
1	.4834	.6952	.4494	59.99	18	.000
2	.1086	.3295	.8698	10.46	10	.401
3	.0243	.1559	.9757	1.84	4	.764
SS Tests v. PMA factors						
1	.4881	.6987	.3878	107.93	24	.000
2	.1494	.3866	.7580	31.58	14	.005
3	.1088	.3298	.8912	13.12	6	.041
SS Factors v. PMA factors						
1	.4694	.6852	.4975	21.98	9	.009
2	.0505	.2247	.9378	2.02	4	.731
3	.0124	.1113	.9876	.39	1	.531

Table 5

Coefficients for the Canonical Variables in the first and second set of the largest canonical correlation in each canonical analysis.

Can. Corr. No.	Variables 1st set	Can. Var. Coefficients	Variables 2nd set	Can. Var. Coefficients
1	figure grouping	-.0518	simultaneous factor	-.8130
	word grouping	-.2301	successive factor	-.4608
	first-last names	-.3107	speed factor	.3558
	word number	-.2542		
	spatial relations	-.4373		
	card rotations	-.1886		
2	Raven's matrices	-.3364	spatial factor	-.5222
	figure copying	-.1102	memory factor	-.4198
	memory for designs	-.3219	reasoning factor	-.3450
	serial recall	-.3219		
	vis. short-term memory	-.1355		
	digit span	-.1087		
	word reading	-.0238		
	colour naming	.2817		
3	simultaneous factor	-.8223	spatial factor	-.5821
	successive factor	-.4497	memory factor	-.4585
	speed factor	.3486	reasoning factor	-.2401

While canonical correlation analyses have shown linear combinations of variables in each set to be significantly related, interpretive difficulties are still present. Canonical correlations give no information about the explained variance of the variables in one set, given the other. Two minor components of each set may correlate highly and produce a high canonical correlation while in reality the overall explained variance of the variables could be small. Redundancy analysis was therefore employed to gain a measure of communality between the sets of variables.

#### Redundancy Analysis.

Thissen and Van Den Wollenberg (1975) state that the objective of redundancy analysis is to construct variates that explain a maximum of variance of the variables of the other set.

Unlike canonical correlation, redundancy analysis is non-symmetric. That is, given two sets of variables X and Y, the redundancy of the X variables will be different to the redundancy of the Y variables. The present analysis indicates this along with providing redundancy measures after rotation (Tables 6, 7 and 8).

Greatest redundancy (.35) existed with the eight SS tests and the PMA factors. As well, a high redundancy also was found with the SS factors and the PMA factors. These communality measures indicate a moderate degree of relatedness between the two test batteries.

Table 6

Redundancy Analysis of the Primary Mental Abilities Battery with the Simultaneous-Successive Factors

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Redundancy of criteria before rotation	= .2279
Redundancy of criteria after rotation	= .2122
Redundancy of predictors before rotation	= .2218
Redundancy of predictors after rotation	= .2255

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Note: Criteria = Simultaneous-Successive factors.

Predictors = Primary Mental Abilities Battery.

Table 7

Redundancy Analysis of the Simultaneous-Successive Battery with the Primary Mental Abilities Factors.

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Redundancy of criteria before rotation	= .3455
Redundancy of criteria after rotation	= .3290
Redundancy of predictors before rotation	= .1829
Redundancy of predictors after rotation	= .1714

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Note: Criteria = Primary Mental Abilities factors.

Predictors = Simultaneous-Successive Battery.

Table 8

Redundancy Analysis of the Simultaneous-Successive Factors with the Primary Mental Abilities Factors

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Redundancy of criteria before rotation	= .2892
Redundancy of criteria after rotation	= .2871
Redundancy of predictors before rotation	= .1774
Redundancy of predictors after rotation	= .1733

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Note: Criteria = Primary Mental Abilities factors.

Predictors = Simultaneous-Successive factors.

#### Discussion

Reanalysis of the psychometric test data presented by Kirby and Das (1978) confirmed some of the original findings and provided additional information about the relationships between the two test batteries.

The findings of the classical factor analyses indicated few differences from the conclusions of the principal component analyses presented by Kirby and Das (1978). Similar factors emerged and factor loadings were found to be somewhat smaller.

Canonical correlations and redundancy analyses allowed for a meaningful interpretation of the relationship between the two test batteries. All three of the canonical correlation coefficients showed only minimal differences. The SS tests which load most heavily in a linear combination with the PMA factors come from the simultaneous, successive and speed test sections of the SS battery. The tests which load only minimally on these factors are those of figure copying, visual short-term memory, digit span and

word reading. These tests from the present analysis constitute what Sternberg (Note 2) refers to as a "trivial variant of a task." (p.6) Their inclusion in the SS battery only contributes minimally to the relationship with the PMA factors. Their empirical validity, the degree of their association with another observable measurement, is therefore in doubt in this present analysis. This is also reflected in the canonical correlations of the PMA tests with the SS factors and in the SS factors with the PMA factors. The tests which are mentioned as contributing little to the canonical correlations load primarily on the successive and speed factors and it is these factors which have predominantly smaller canonical coefficients. These tests appear to have limited relevance for inclusion in a battery of tests predictive of performance of the PMA battery.

The degree of communality between the two test batteries provides a measure of the validity of the SS tests and factors. The redundancy value of .345 of the SS tests with the PMA factors indicates a meaningful amount of shared variance and hence the empirical validity of the SS battery is confirmed by the present analysis. Interestingly, a redundancy score of .289 was obtained for the SS factors and the PMA factors. Common variance was lost through factorization of the SS battery, in which three factors were extracted from a total of eight tests.

The present analyses identify the relatedness of the SS tests with tests representative of a more traditional model of primary mental abilities. The limited influence of some of the SS tests has been underlined and the need for further variations of tests in measuring the simultaneous successive hypothesis is indicated. Carroll (1978) comments that it is pure inference that what is involved in simultaneous successive processing is in fact measured by the SS tests. He suggests therefore that further tests need to demonstrate these processes in a variety of settings. Appropriate analytic procedures might then be used to establish the validity of such tests in measuring this model of information processing.

#### Reference Notes

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