Some further evidence on successive and simultaneous integration and individual differences

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ABSTRACT

Hierarchical factor structures of 11 cognitive tasks for 169 10-year-old boys and 158 10-year-old girls are discussed. Three of these tasks were investigated by classifying children as low and high on the basis of a median split of simultaneous and successive factor scores obtained from the other eight tasks. Visual-Reconstruction (V-R), Visual-Verbal (V-VL), and Verbal-Reconstruction (VL-R) tasks, when used as dependent variable vectors, indicated significant simultaneous and successive MANOVA effects. A significant simultaneous × successive interaction was obtained for V-VL and VL-R tasks. The results are discussed in terms of developmental hemispheric lateralization and integrational synthesis.

Das (1973) has proposed a new model of cognitive abilities based on Luria's (1966a, b) work. He proposed as alternatives to reasoning and memory two modes of information integration, simultaneous and successive, and showed the existence and generality of these two processes by a factor analysis study of the cognitive test scores of 9- to 11-year-old children from Canada and India. In another factor analytic study, Das and Molloy (1975) found that simultaneous, successive, and speed factors existed in each of grade one and grade four samples. In this particular study, one of the questions considered was whether or not the three factors identified were orthogonal to school achievement. Das (1973) had found that a school achievement factor based on tests of reading and mathematics achievement and IQ was "independent" of the other three factors. Again, Das and Molloy (1975) found that reading achievement emerged as a separate factor with significant loadings on the vocabulary and comprehension subscores of the reading achievement test. Their final exploratory factor analysis involving 14 measures of grade four children did not include the two reading achievement, vocabulary, and comprehension scores. As a result of this factor analysis they identified five factors as successive, simultaneous, socio-economic-status-cultural, speed, and spatial imagery which they found difficult to explain.

McGlone (Note 1) has demonstrated sex differences in functional brain asymmetry, and the reliability of the sex variable in cognitive tasks has been established without question (see Bloom, 1964). Is it not, therefore, reasonable to expect different factor structures on successive and simultaneous tasks for male and female subjects? The first part of the present study deals with such differences in factor structures although it is not the primary import of the study.

The simultaneous and successive syntheses may exhibit individual differences and show developmental differentiation (Jarman, 1978). However, the nature of these processes in terms of tasks of specific structure and complexity is quite elusive. The factors identified as simultaneous and successive syntheses were uncorrelated with achievement variables (Das, 1973; Das & Molloy, 1975). Also, French (1951) and Horn (1972) reported ability factors which were orthogonal to the achievement factor. The functioning of the occipital-parietal and the anterior cerebral cortical regions, the basis for the two integrative processes, simultaneous and successive respectively, should be related to school performance. Factor analysis procedure, in and of itself, may not show the predictability of school performance by the two syntheses. Perhaps school achievement and other complex tasks are dependent on the two processes working interactively. The factor analysis procedure used by previous investigators may not be appropriate for such questions. In fact, Kirby and Das (1977) have shown that successive and simultaneous factor scores do correlate significantly with vocabulary and comprehension subscores of the Gates-MacGinitie reading test. A major purpose of this investigation was to determine how the two processes operate in the context of variables of known characteristics.

METHOD

Subjects

From a western Canadian urban school system 327 10-year-old children were tested. Of these, 169 were male and 158 were female. The principals of the participating schools in the system provided lists of eligible students in their respective schools for whom parental permission had been granted for participation in the study.

Testing

The following test battery was given to each child by four testers over a period of two days in classroom groups at each school. All procedures were standardized and instructions given by tape recorders.

Gapadol Test

This test was developed by McLeod and Anderson (1970). Essentially this is a reading ability test based on the Cloze technique which requires students to fill in words randomly omitted from prose material. Both forms, form G and form Y, were administered. Because of the requirement of students to link preceding and following words in order to fill in the blank, it was thought that these test forms should measure successive synthesis.

Patterns Tests

These tests consist of 40 shapes each drawn on a 3 × 3 square dot matrix. Each shape had been analyzed for difficulty and item discrimination. The first test, patterns A, consists of the momentary presentation by slide of 20 of the shapes. The subject is required to reproduce the shape immediately after its presentation on a supplied dot matrix. The second test, patterns B, consists of the presentation of the other 20 shapes, but in this instance the subject is required to reproduce on the dot matrix the inverted shape involving a rotation of 180°. From the work of Luria (1966a, b, 1973) and Das (1973) these tests should measure simultaneous synthesis.

Digit and Letter Span Tests

Two digit span and two letter span tests were constructed. The digit span tests consisted of the oral presentation of digits at ½ second and 1 second intervals between digits respectively, and the letter span tests consisted of the oral presentation of letters at ½ second and 1 second intervals between letters respectively. The letters and digits were those used in the letter span and digit span of the *Kit of Reference Tests for Cognitive Factors* (French, Ekstrom & Price, 1963). The subject was required to write down the digits/letters in the order in which they had been read. Das, Kirby and Jarman (1975) have shown that this type of test involves successive processing.

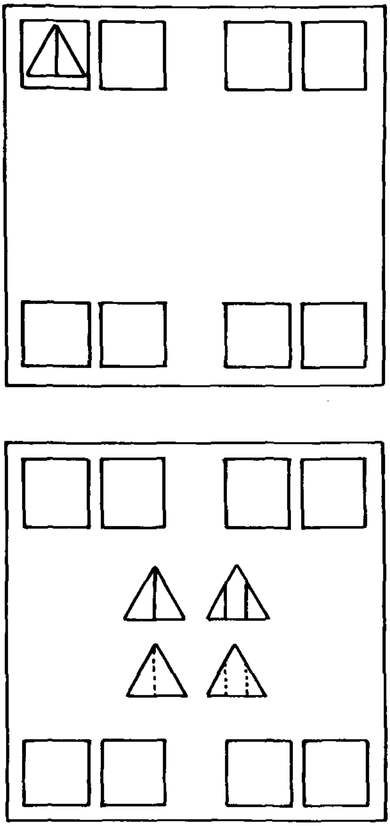
Perceptual Tasks

The perceptual information processing tasks were administered approximately two weeks after the administration of the tests mentioned above. These tasks were based on information theory in order to vary complexity within each set. Each set of tasks consisted of two each of complexity one to eight bits defined in terms of relevant cues within a set. For example, a task of one bit complexity requires only one binary decision and that of eight bit complexity would require eight such decisions. A binary decision is a choice between two alternatives such as green or red. The first structural combination, visual-reconstruction (V-R), was comprised of a momentary presentation of a slide of a geometric design. This was followed by the second slide containing a number of elements depending upon the complexity (2^n), where n is the complexity in bits. The respondents were required to mark "X" in the spaces on the answer sheet in the presence of the second slide so that their choice(s), at most two, would make the original design. The construction of stimulus materials and the contextual alternatives are explained in Randhawa (1972). However, in the present study a group testing procedure was used and the materials were adopted for this purpose. An example of a stimulus, the contextual slide, and the response sheet for a 5-bit task in the V-R combination is provided in Figure 1.

The second structural combination, visual-verbal (V-VL), consisted of momentary presentation of a slide of a geometric design which was followed by the second slide exactly as in the V-R tasks. The respondents were required to place an "X" beside one element of each of the pairs of word cues in the answer booklet so that their choices would enable a person to pick the appropriate elements from the second slide to make the original design. An example of the V-VL stimulus, contextual slide, and response sheet for a 5-bit task is provided in Figure 2.

The third structural combination, verbal-reconstruction (VL-R), consisted of a momentary presentation of a vertical list of word cues. The students were then shown the second slide as in tasks V-R and V-VL. In the presence of this second slide the respondents marked an "X" in the spaces corresponding to the elements as required in task V-R, so that their choice(s) contained all the properties enumerated in the first slide. An example of the VL-R stimulus, contextual slide, and response sheet for a 2-bit task is given in Figure 3.

The 16 tasks within each structural combination were randomized. The three structural sets were presented to a group of students in a school in one of the four random orders. Approximately the same number of students were tested with each of the four orders of structural sets.



LEFT ________ ONE ________

RIGHT ________ TWO ________

TOP ________ SOLID ________

BOTTOM ________ DOTTED ________

YELLOW ________

BLUE ________

FIGURE 1
An example of a visual-reconstruction (V-R] *task of 5-bit complexity* (a) *The stimulus slide,* (b) *the contextual slide, and* (c) *the response sheet.*

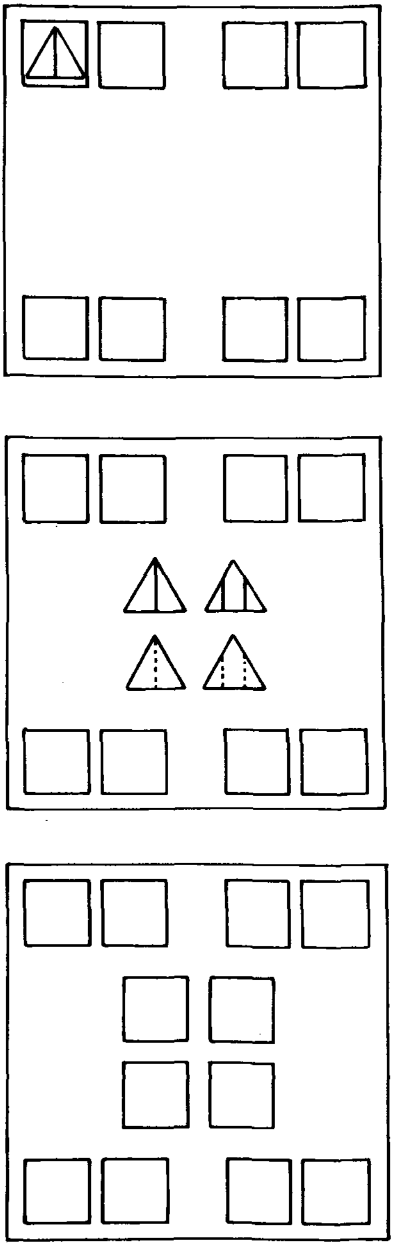


FIGURE 2
An example of a visual-verbal (V-VL) *task of 5-bit complexity.* (a) *The stimulus slide*, (b) *the contextual slide, and* (c) *the response sheet.*

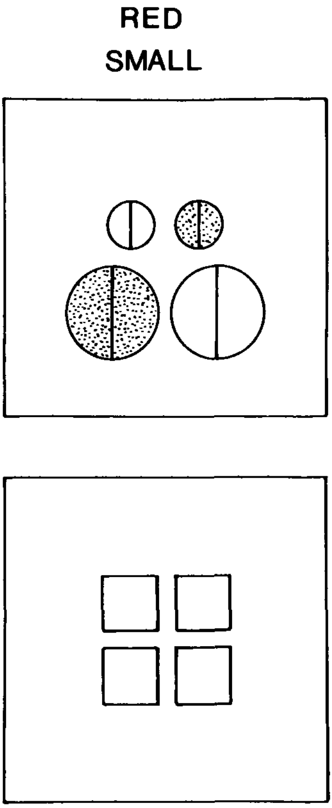


FIGURE 3
An example of a verbal-reconstruction (VL-R) *task of 2-bit complexity.* (a) *The stimulus slide,* (b) *the contextual slide, and* (c) *the response sheet.*

However, due to errors in the answer sheet for the 4- and 5-bit tasks of the VL-R set, only 12 tasks were included in the analysis reported here for this set.

Scoring

Each response within a structural set was scored for the number of correct relevant cues (bits) and the average of each of the two tasks at each complexity level was obtained for each respondent. Also, the total score for all the tasks in a set was obtained for use in the factor analysis.

ANALYSIS, RESULTS, AND DISCUSSION

For the male and female groups, correlation matrices of the 11 variables and communality estimates from the principal factor solution (Harman, 1967) are presented in Table 1. The correlation matrices were analyzed by

TABLE 1

Female (upper diagonal) and male (lower diagonal) correlation matrices and communality estimates[a]

Variable		1	2	3	4	5	6	7	8	9	10	11
		(896)	(752)	(664)	(691)	(399)	(423)	(454)	(379)	(240)	(366)	(639)
1. Gapadol G	(833)	—	840	171	255	225	−138	364	−071	246	272	252
2. Gapadol Y	(857)	839	—	236	317	251	−093	311	−002	286	243	215
3. Patterns A	(604)	134	068	—	636	138	152	238	183	255	315	190
4. Patterns B	(502)	192	215	528	—	140	017	293	087	220	301	083
5. Digit Span (½ sec)	(555)	191	175	105	118	—	287	488	284	004	019	093
6. Digit Span (1 sec)	(218)	119	118	077	129	344	—	240	438	−029	−184	−084
7. Letter Span (½ sec)	(123)	148	198	142	195	220	092	—	274	032	013	016
8. Letter Span (1 sec)	(412)	211	187	−007	133	462	280	213	—	−055	−165	−092
9. Visual Reconstruction	(418)	184	278	176	266	119	138	126	088	—	283	342
10. Visual Verbal	(287)	246	262	217	258	001	119	065	057	311	—	278
11. Verbal Reconstruction	(689)	388	406	248	285	075	180	105	141	538	442	—

[a]Communality estimates are in parentheses. Both the communality estimates and correlation coefficients are rounded off to three places of decimal and the decimal is omitted.

TABLE 2

Hierarchical factor solution for males and females

Variable	Factors[a] Females (N = 158) IB	IIB	IIIA	IVA	VA	VIA[b]	Males (N = 169) IB	IIA	IIIA	IVA	VA
1. Gapadol G	52	05	79	−02	−05	00	51	76	−02	01	02
2. Gapadol Y	51	09	69	−00	03	−01	54	74	05	−00	−04
3. Patterns A	52	21	−11	05	58	04	36	−03	−05	−04	68
4. Patterns B	49	14	05	−01	64	−13	44	02	03	04	55
5. Digit Span (½ sec)	19	53	17	20	−06	08	26	−00	−05	69	02
6. Digit Span (1 sec)	−05	57	−19	23	01	04	26	−06	09	39	−02
7. Letter Span (½ sec)	24	54	27	17	08	−05	22	07	−02	24	13
8. Letter Span (1 sec)	−01	56	−12	21	06	−01	26	03	01	58	−07
9. Visual Reconstruction	40	−09	07	−01	11	23	51	−06	40	02	−01
10. Visual Verbal	47	−22	06	−07	19	23	43	04	28	−09	08
11. Verbal Reconstruction	52	−14	−02	03	−12	57	66	04	49	−05	−03

[a]Rounded off to two places of decimal; the decimal is omitted.
[b]The A are the first-order and the B are the second-order factors.

TABLE 3
Varimax factor loadings and communalities for the Patterns, Gapadol, and Digit-Letters Tests ($N = 327$)

Variable	Factor loadings 1	2	3	h^2
Gapadol G	17	93	07	90
Gapadol Y	16	94	08	91
Patterns A	12	−01	89	80
Patterns B	09	16	87	79
Digit ($\frac{1}{2}$ sec)	73	26	05	60
Digit (1 sec)	83	−02	07	69
Letters ($\frac{1}{2}$ sec)	63	29	16	50
Letters (1 sec)	73	06	08	55

Note. Decimals omitted.

the hierarchical factor solution (Schmid & Leiman, 1957). It should be emphasized that the proposed solution does not sacrifice the ease of psychological interpretation and that what is concealed in the intercorrelations of the oblique axes provides added meaning in terms of the progressive groupings of the variables at higher levels. The factor solutions for the males and females are provided in Table 2. Four first-order and two second-order factors were obtained for the female group. Four first-order and one second-order factors were obtained for the male group. As postulated, these two factor structures are different. This conclusion should become clear from the interpretations given below.

Factors IB and IIB, the two second-order factors for the female group, define general cognitive processes and memory respectively. However, the four first-order factors, IIIA, IVA, and VA, and VIA, can be defined as successive synthesis, memory, simultaneous synthesis, and integrative synthesis. These interpretations are based on the loadings of the variables on the respective factors in such a way that at any level of factor solution one and only one factor is loaded by a variable.

For the male group, however, Factor IB, the only second-order factor, is the general factor. Factors IIA, IIIA, IVA, and VA, the four first-order factors, can be defined as successive synthesis, integrative synthesis, memory, and simultaneous synthesis respectively. The four first-order factors for boys and girls are virtually the same. However, females show cognitive differentiation at the higher order which has not yet resulted in the boys (Bloom, 1964; McGlone, Note 1).

The eight test scores of the first battery for the total group were intercorrelated and factor analyzed using the principal factor method (Harman, 1967). The resulting factor structure was orthogonally rotated, involving the varimax solution which is given in Table 3. With the resulting varimax factor structure, using the formula, $F = P'R^{-1}Z$, factor scores for each of the 327 students were obtained and transformed to a mean of 100 and a standard deviation of 15. In terms of the design of the present study, a 2 × 2 × 2 multivariate and univariate ANOVA, a decision had to be made at this point. Factor III was obviously the simultaneous synthesis factor. For the purpose of the present study it was decided to take Factor II as the successive synthesis factor. A median split of the resulting factor scores using these two factors was then made so that each student was placed in one quadrant of a four-quadrant, two-dimensional model of successive-simultaneous competence. The third factor in the design was sex.

The results of ANOVA on each set follow:

V-R Structure

The means of girls on the eight tasks were higher than those of the boys, but the multivariate F-ratio for the sex effect was only marginally significant ($F(8,312) = 1.69$, $p < 10$). The corresponding univariate F-ratios were significant for 3-, 6-, and 8-bit tasks ($p < .05$). The high successive group was significantly superior to the low successive group ($F(8,312) = 2.65, p < .01$). As shown in Table 4, all but two of the corresponding univariate F-ratios were also significant. The significant multivariate F-ratio for the simultaneous factor ($F(8,312) = 1.95, p < .05$) indicated, as expected, that the high simultaneous group was superior to the low simultaneous group. All but two of the corresponding F-ratios were also significant. No significant interactions were obtained. The significant successive and simultaneous main effects and the lack of 2-way interaction would indicate that these two processes may be equally appropriate in processing information in the V-R structure.

V-VL Structure

Within-variances and mean vectors for the main effects are provided in Table 5. The multivariate F-ratio for the sex factor was not significant. The multivariate F-ratio for the successive factor was significant ($F(8,312) = 4.44, p < .01$) and the corresponding univariate F-ratios were significant for all the tasks except the easiest 1-bit task. The simultaneous factor was also significant ($F(8,312) = 2.89$, $p < .01$). The corresponding univariate F-ratios for the simultaneous factor were significant for 5- to 8-bit tasks. As the tasks become more difficult, simultaneous synthesis is significantly more effective in processing such tasks.

The multivariate successive × simultaneous interaction was significant ($F(8,312) = 2.04$, $p < .05$). The univariate significant interaction was obtained only for 5- and 6-bit tasks. This is obviously due to the ceiling effect on the simpler tasks and random guessing on the most difficult tasks

TABLE 4

Within-variance and means on the main effects for the V–R tasks in the 2 × 2 × 2 design

Task (Bits)[a]	Within-variance	Successive		Simultaneous		Sex	
		Low (159)	High (168)	Low (164)	High (163)	Male (169)	Female (158)
1	.04	.91*	.96	.90*	.96	.93	.94
2	.11	1.63	1.69	1.62*	1.67	1.65	1.67
3	.19	2.74*	2.91	2.77*	2.88	2.77*	2.88
4	.53	3.52*	3.79	3.62	3.70	3.59	3.73
5	.70	4.34*	4.68	4.38*	4.65	4.48	4.56
6	1.07	5.16*	5.49	5.26	5.41	5.19*	5.49
7	1.40	6.20	6.45	6.19*	6.47	6.21	6.46
8	2.18	6.47*	6.97	6.53*	6.93	6.48*	7.00
Average	.36	3.87*	4.12	3.91*	4.09	3.91*	4.09

Note. Numbers in parentheses indicate the number of children in each subgroup.

[a]This is also the maximum score on each task.

*Significant at the .05 level.

TABLE 5

Within-variance and means on the main effects for the V-VL tasks in the 2 × 2 × 2 design

Task (bits)[a]	Within-variance	Successive		Simultaneous		Sex	
		Low	High	Low	High	Male	Female
1	.08	.90	.90	.91	.89	.88	.92
2	.27	1.39*	1.61	1.46	1.54	1.43*	1.58
3	.59	2.03*	2.30	2.12	2.22	2.12	2.21
4	.98	2.68*	3.06	2.78	2.96	2.79	2.96
5	1.94	2.76*	3.13	2.67*	3.23	2.84	3.06
6	1.62	2.98*	3.37	2.99*	3.36	3.04*	3.32
7	3.07	2.55*	3.51	2.68*	3.40	3.04	3.04
8	2.93	3.37*	4.05	3.51*	3.92	3.53*	3.92
Average	.53	2.33*	2.74	2.39*	2.69	2.46*	2.63

[a]This is also the maximum score on each task.
*Significant at the .05 level.

TABLE 6

Combined means on successive × simultaneous interaction for the V-VL tasks in the three factor design

Task (bits)[a]	Group			
	Lo-Lo (79)	Lo-Hi (80)	Hi-Lo (85)	Hi-Hi (83)
1	.91	.88	.90	.90
2	1.38	1.40	1.54	1.68
3	2.01	2.06	2.22	2.37
4	2.68	2.67	2.87	3.24
5	2.75*	2.77	2.60	3.67
6	2.96*	3.00	3.03	3.72
7	2.31	2.79	3.04	3.99
8	3.23	3.51	3.77	4.33
Average	2.28*	2.38	2.49	2.99

Note. Numbers in parentheses indicate the number of children in each subgroup.
[a]This is also the maximum score on each task.
*Significant at the .05 level.

after the channel capacity (maximum performance) was reached at the level of discriminating tasks. The performance of the four groups appears to have reached asymptotic levels when tasks of 5- and 6-bits were presented. This fact is clearly demonstrated by the channel capacity levels given in Table 6. These levels clearly demonstrate that for such tasks successive synthesis provides differential advantage only when the simultaneous synthesis is high. These findings provide support for the interpretation of the data in Kirby and Das (1977) that both syntheses are necessary, and neither by itself is sufficient, for high performance. Hunt, Ran-

TABLE 7
Within-variance and means on the main effects for the VL-R tasks in the 2 × 2 × 2 design

Task (bits)[a]	Within-variance	Successive		Simultaneous		Sex	
		Low	High	Low	High	Male	Female
1	.01	0.97*	1.00	.98*	1.00	.98	0.99
2	.06	1.90*	1.97	1.91*	1.96	1.90*	1.97
3	.32	2.61*	2.80	2.63*	2.78	2.61*	2.81
6	1.70	3.17*	3.92	3.46	3.65	3.36*	3.76
7	2.64	2.96*	3.67	3.24	3.41	3.13*	3.53
8	3.13	3.02*	3.79	3.21*	3.62	3.32	3.51
Average	.23	1.83*	2.14	1.93*	2.05	1.91*	2.07

[a]This is also the maximum score on each task.
*Significant at the .05 level.

dhawa, and Fitzgerald (Note 2) found some evidence for such a differential advantage in rote and semantic short-term retention of verbal material as successive synthesis increased. They also found evidence for an interactive role of the two syntheses in long-term retention.

VL-R Structure

The sex factor was significant ($F(6,314) = 3.08$, $p < .01$). This result coupled with the examination of the mean vectors (see Table 7) for boys and girls indicated that girls were generally superior to boys in processing the VL-R tasks. McGlone (Note 1) suggests that a greater degree of brain functional and structural asymmetry is found in men than in women. However, developmental studies indicate that girls show earlier and stronger lateralization of speech, motor, and sense functions compared to boys. Left hemisphere dominance may in fact establish itself sooner in females, a maturational advantage which fits well with their reported superiority to males on certain speech related tasks. Ultimately, however, adult females appear to be less lateralized than males for verbal and spatial functions. Maturational and interhemispheric integrational differences in boys and girls in the present population may, in part, account for the sex differences.

The overall successive factor ($F(6,314) = 5.35$, $p < .01$) and the simultaneous factor ($F(6,314) = 2.47$, $p < .01$) were significant. Within-variance and means on these main effects are provided in Table 7. All the corresponding univariate F-ratios on the successive factor were significant. All but two of the corresponding univariate F-ratios were significant on the simultaneous factor. As expected, either of the two syntheses was effective in processing VL-R tasks. However, the successive × simultaneous in-

TABLE 8
Combined means on successive × simultaneous interaction for the VL-R tasks in the three factor design

Task (bits)[a]	Group Lo-Lo	Lo-Hi	Hi-Lo	Hi-Hi
1	.95*	1.00	1.00	1.00
2	1.84	1.95	1.97	1.97
3	2.55	2.68	2.71	2.88
6	3.27*	3.07	3.64	4.20
7	2.97	2.95	3.49	3.85
8	2.97	3.07	3.43	4.15
Average	1.82*	1.84	2.03	2.26

[a]This is also the maximum score on each task.
*Significant at the .05 level.

teraction ($F(6,314) = 3.68$, $p < .01$) indicates that children with superior successive synthesis had differential advantage over those with inferior successive synthesis only when their simultaneous synthesis was superior. Combined means for this interaction are given in Table 8. The critical univariate interaction was obtained for tasks of 6-bit complexity. These tasks, as in V-VL structure, provided the asymptotic and discriminative performance of the groups. Again, on these tasks high performance results from high levels of successive and simultaneous processing of information in an interactive fashion (Kirby & Das, 1977).

Educational and Research Implications

It is clear that the successive/simultaneous synthesis model springs from a conceptualization of the cerebral cortical functioning of humans. A proper operationalization of this model should be based on theoretically and educationally relevant tasks.

Luria's conceptualization of brain functions and the dynamic integration between the two hemispheres is promising. Present clinical and neuropsychological evidence indicates that besides the functional independence between the successive and simultaneous syntheses, an interactive process is operative in the integration of the two hemispheres of the brain in processing tasks that require the simultaneous action of the two cerebral hemispheres (Bogen, 1969; Luria, 1973).

The results of the present study substantiate the previous evidence. Task specific behaviors of a variety of individuals in the normal population range should be studied to determine whether an individual uses simultaneous, successive, or both in coping with the demands of a task. Then these individual dispositions on specific tasks can be investigated to determine their appropriateness for instructional tasks ranging in nature from simple to complex. It is conceivable that different individuals might employ different syntheses for the same task depending on their preferences, prior learning history, and general cognitive orientation (Jarman, 1978). The stability and endurance of these preferences over a range of tasks is an issue that is far from resolved. Generalizability of stylistic preferences across different domains requires a careful and systematic study. Studies done by Das and his associates and the present study contribute only modestly in this regard.

An important concern in instructional planning for normal and exceptional children is to know beforehand, in a macroscopic sense, what specific syntheses are most suitable for a given task, given the available instructional resources. A beginning in this context can be made with already existing instruments, by examining their nature in terms of the specific syntheses that they require. Of course, that should not limit those with creative drive to develop new measures for the classification of individuals as habitually successive, simultaneous, or dual modal processors.

RÉSUMÉ

Discussion des structures factorielles hiérarchiques de 11 tâches cognitives chez 169 garçons de dix ans et 158 filles de 10 ans. L'analyse de ces trois tâches est fondée sur une classification des enfants (niveau supérieur *vs* niveau inférieur) à partir de la médiane des cotes factorielles successives et simultanées observées dans les huit autres tâches. Les résultats obtenus dans les tâches reconstruction visuelle (V-R), visuelle-verbale (V-VL) et reconstruction verbale (VL-R), quand on les utilise comme vecteurs de variable dépendante, révèlent des effets MANOVA successifs et simultanés. On trouve également une interaction significative entre les cotes simultanées et successives pour les tâches V-VL et VL-R. L'interprétation fait intervenir le développement de la latéralisation hémisphérique et la synthèse intégrative.

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