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LEFT AND RIGHT INTELLIGENCE: CASE STUDIES OF RAVEN'S PROGRESSIVE MATRICES FOLLOWING BRAIN BISECTION AND HEMIDECORTICATION[1]

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The visual and nonverbal Raven Progressive Matrices (RPM) test would seem to offer high promise as a test for determining possible laterality components in intelligence. Response to the Raven problems requires neither verbalization nor skilled manipulative ability nor subtle differentiation of visuo-spatial data (Basso, De Renzi, Faglioni, Scotti and Spinnler, 1973). Verbal instruction is kept to a minimum and the progression of the test items serves as training. The apparent reliance of the Matrices on minimal linguistic and manipulative abilities, has also made it a popular measure of intelligence in neurologic patients with focal lesions and associated aphasia and apraxia.

The evidence, however, from results to date in patients with asymmetric cerebral pathology is conflicting and inconclusive. There is no general agreement even on whether the presence of a focal unilateral lesion depresses scores on the Raven Progressive Matrices. Neither patients with unilateral temporal lobectomies (Meyer, Jones and Gwynne, 1957) nor patients with penetrating missile wounds of diverse localizations (Newcombe, 1969) showed a significant deficit on the Raven relative to non-brain-damaged controls. Nor did either group show a significant laterality effect. Unselected patients with unilateral cerebrovascular accidents or neoplastic lesions often do show significant deficits relative to controls (e.g., Costa and Vaughan, 1962; Costa, Vaughan, Horwitz and Ritter, 1969; Arrigoni and De Renzi, 1964; De Renzi and Faglioni, 1965) but occasionally do not (Van Dongen, 1973). Even a brain-damaged population selected to have no deficit in auditory language comprehension, had significantly lower matrices scores than did controls (Boller and Vignolo, 1966).

Conflicting laterality effects are also reported for unselected (primarily

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vascular) patients. Some studies report significantly bigger deficits with left hemisphere lesions (Arrigoni and De Renzi, 1964; Kertesz and McCabe, 1975), others report significantly inferior performance following right sided insult (Archibald, Wepman and Jones, 1967a; Costa et al., 1969; Van Harskamp, 1973; Messerli and Tissot, 1973), while still others report no significant difference between left and right brain damage (Costa and Vaughan, 1962; Basso et al., 1973; De Renzi and Faglioni, 1965; Colonna and Faglioni, 1966).

Some headway into resolving these conflicts was made by analyzing the effects on Raven Progressive Matrices scores of the presence of aphasia with and without constructional apraxia, and inspecting the differential effects of several clinical types of aphasia. The effect of aphasia alone is still muddled; some researchers report that left brain-damaged aphasics are significantly inferior to non-aphasic patients with left cerebral insults (Costa et al., 1969; Basso et al., 1973; Colonna and Faglioni, 1966) but others find no such differences (Piercy and Smith, 1962; Archibald et al., 1967a, 1967b; Arrigoni and De Renzi, 1964; De Renzi and Faglioni, 1965; Boller and Vignolo, 1966, for exclusively expressive aphasics; Kertesz and McCabe, 1975; Van Dongen, 1973; Messerli and Tissot, 1973). Concerning the differential performance of aphasic types, there is some consensus that severe receptive aphasics with posterior localization show selective deficit on the Progressive Matrices (Costa et al., 1969; Kertesz and McCabe, 1975; Zangwill, 1964; and perhaps also Archibald et al., 1967a, 1967b). Still, Basso et al. (1973) found no difference on RPM scores between fluent and nonfluent aphasics, whereas others found a significant correlation between the severity of aphasia and degree of impairment on the RPM (Costa and Vaughan, 1962; Van Harskamp, 1973) although this again is disputed by the Italian results (Basso et al., 1973). However, there is general agreement that construction apraxia resulting from lesions of either hemisphere is likely to reduce RPM scores.

Recently, accounting for prior conflicting data, Basso et al. (1973) postulated two cerebral areas whose integrity is necessary for normal performance on the RPM: an area in the left hemisphere partially coextensive with the language region, and an area in the posterior part of the right hemisphere. Costa (1976) in turn suggested that the Raven Colored Progressive Matrices (RCPM) does not have a homogeneous laterality index across sets. Denes, Semenza and Stoppa (1979) confirmed this prediction by showing selective improvement on different sets of the RCPM following left and right brain damage.

An alternative approach to the "laterality index" of the RPM is to analyze its factorial structure (Burke, 1958; Bingham, Burke and Murray, 1966; Burke and Bingham, 1969) relative to tests with known laterality indices. By far the most direct method, however, is to compare directly the scores of isolated left and right hemispheres following hemispherectomy for postinfantile damage, or of those of the matched disconnected left and right hemispheres in patients with cerebral commissurotomy. A recent study on commissurotomy patients (D. Zaidel and Sperry, 1973) using a tactile-visual cross-modal modification of the RCPM, showed left hand superiority but above chance performance in either hand. The answers in that test had to be sought among a choice of three metal-etched patterns in blind tactual exploration, rather than in free vision in the usual manner. Consequently, the scores could not be compared directly, either with the standardization group or with patients with unilateral hemispheric damage, so that the possibility of bilateral deficit or of a modality specific laterality effect following commissurotomy could not be ruled out.

It thus seemed important to readminister the RPM in the standard forms to commissurotomy and also to hemispherectomy patients. The scores obtained from both the Raven Colored (RCPM) and Standard Progressive Matrices test (RSPM) could then be compared directly with the norms and with brain-damaged patients. In addition, the board form of the Colored Matrices, which allows for trial-and-error, was administered to the brain-bisected and hemidecorticated patients in order to tap possible hemispheric asymmetries in error correction.

In principle, one can study empirically the relation of hemispheric specialization to intelligence by comparing left and right hemisphere performances on the tests which define the principal intellectual factors of a given theory of intelligence. It is natural (though not necessarily correct) to conceive of different primary or special abilities as sustained by distinct cerebral regions and as dissociable from each other by focal lesions. But then the question arises as to the left-right status of general intelligence or "g" as conceived by the British school of intelligence. This hierarchical theory of intelligence postulates a superordinate general ability ("g") which enters into all intellectual performances and which is distinct from a number of subordinate special aptitudes denoted by group factors (e.g., verbal, numerical, and visuo-spatial). Spearman (1923) believed "g" to be a homogeneous function of the human cerebral cortex, in conformity with Lashley's principles of mass action and equipotentiality.

It is particularly interesting, therefore, to find the distribution of "g" in the two cerebral hemispheres. This could determine, first, whether there is a sense in which one hemisphere can still be said to be more intelligent than the other. Secondly, the answer could help determine the physiological validity of the British special abilities model of intelligence. The British model would predict equal competence by either hemisphere on a pure test of "g". Since the Matrices test was considered by Spearman to be perhaps the best of all nonverbal tests of "g", this measure is ideal for assessing the intelligence of each cerebral hemisphere and determining possible laterality effects in "g".

Material and Method

Subjects

The subjects included two complete commissurotomy patients of Dr. P.J. Vogel and Dr. J.E. Bogen of Los Angeles, L.B. and N.G., believed to have minimal extracallosal damage relative to the whole Vogel-Bogen commissurotomy patient group (Sperry, Gazzaniga and Bogen, 1969). The other two subjects were post-infantile hemispherectomy patients. D. W., a patient of Dr. I. G. Gill, was left handed prior to right hemispherectomy as are two of his brothers, but a pre-surgical sodium amytal test showed left hemisphere dominance for speech. R.S. was a formerly right handed dominant hemispherectomy patient of Drs. J.E. Bogen and P.J. Vogel. Table I summarizes the case histories. For further clinical information, see Bogen, Fisher and Vogel (1965), Sperry et al. (1969), Bogen (1969), Bogen and Vogel (1975), Gott (1973), and Zaidel (1973).

Procedure

The two commissurotomy subjects wore on their right, dominant, eyes individually molded scleral contact lenses constructed to permit continuously lateralized visual presentation with free ocular scanning of the stimuli (Zaidel, 1975). A small screen occluding one half of the visual field was supported on the lens close to the eye and followed the patient's eye movements faithfully, located on the same plane at which a reduced aerial image of the stimulus was projected. A 100 diopter collimating lens attached to the scleral lens enabled the patient to focus on the stimulus close by, so that it appeared normal in size and did not require accommodation. Thus, a stabilized image of the occluding screen was constantly superimposed on the stationary image of the stimulus. The left eye was covered by an eye patch during testing. The method of supporting the optical components used to reduce and project the stimulus image close to the eye was revised slightly from Zaidel (1975).

The test was placed on a stimulus board in the subject's lap. The image of the board and of the subject's hand on it was projected by a mirror/lens system close to the subject's eye. Thus, the patient could visually monitor his/her hand movement during test performance with one half-field at a time.

The RSPM and RCPM consist of 5 and 3 sets, respectively, with 12 progressively more difficult test items in each set. The book form of the RCPM (Raven, 1962) was administered to each commissurotomy patient first in the left visual half field with left hand pointing to one out of six choices; a week later in the right visual half field with right hand pointing to the answers; and finally, yet another week later, in free vision. This order was fixed for both subjects since a long experience of testing these patients has shown that the left hemisphere is less likely to interfere with right hemisphere performance when it is new to the task. This procedure cannot result in a left hemisphere advantage due to practice effects insofar as the disconnected left hemispheres are consistently unaware of the previous testing experiences of their sister right hemispheres when questioned verbally in great detail. The book form of RSPM (Raven, 1958) was

TABLE I

Summary of Case Histories

Patient	Sex	Reason for surgery	Surgery	Age at surgery	Years postop. at testing	Age at onset of symptoms	IQ history* Preop.	IQ history* Postop.
N.G.	F	Intractable epilepsy	Complete cerebral commissurotomy: Single stage midline section of anterior commissures, corpus callosum (and presumably psalterium), massa intermedia and right fornix. Surgical approach by retraction of the right hemisphere.	30	9	18	Wechsler-Bellevue 76 (79,74) at age 30	WAIS 77 (83, 71) at age 35
L.B.	M	Intractable epilepsy	As above but massa intermedia absent.	13	7	3:6	WISC 113 (119, 108) at age 13	WAIS 106 (110, 100) at age 14
R.S.	F	Glioma	Left (dominant) hemispherectomy including caudate nucleus and upper portion of thalamus. Partial tumor removal via a left parietal incision at age 8.	10	3	8	Kuhlman-Anderson 100 at age 8	WISC 56 (63, 55) at age 13
D.W.	M	Intractable epilepsy	Right hemispherectomy presumably sparing basal ganglia and thalamus. Frontal lobectomy at age 6:11.	7:9	9	6:7	Stanford-Binct 125 at age 3:6	WISC 67 (80, 60) at age 16:6

* WISC and WAIS scores are expressed: Full scale IQ (verbal IQ, performance IQ).

admistered in the same sequence a month later. The book forms of the tests were presented in free vision in the standard manner to each of the two hemispherectomy patients.

The board form of the test was administered to the same patients (except for R.S. who had died due to recurrence of tumor at the age of 17) in the same order from 4 to 3 years later. In this form, each problem appears on a board with a part removed. The answers consist of 6 moveable pieces, each of which exactly fits the space in the board. The subject is encouraged to use a trial and error approach to different solutions until he is satisfied with the answer. Like the book form, the board form of the Colored Matrices was administered in one visual half field at a time. The hand ipsilateral to the stimulated field manipulated the moveable pieces.

Results

Laterality

Tables II and III summarize the raw scores on the book and board forms of the RCPM. As was found with the tactile modification of Raven's Colored Progressive Matrices by D. Zaidel and Sperry, the disconnected right hemisphere of N.G. showed an advantage on the RCPM in the book form relative to the left (Table II) though, again, this left-right difference is statistically insignificant. L.B.'s scores show a ceiling effect but the 1 point advantage of his right hemisphere over his left hemisphere was duplicated in a subsequent administration of the test. By contrast, scores on the longer and more difficult RSPM reveaded a nonsignificant left hemi-

TABLE II

Performance on the Book and Board Form of Raven's Coloured Progressive Matrices (RCPM). Maximum Score = 36. LH = left hemisphere; RH = right hemisphere.

		Book form			Board form					
						Raw score		Difference		
Patient	Hemisphere tested	Age at testing	Raw score	Age estimate	Age at testing	First attempt	Last attempt	Board last-first	Board-book last	Age estimate
N.G.	RH	40	25	10:3	43:8	16	25	9	0	>9:6
	LH		20	8:6		18	28	10	8	>9:6
	BI		20	8:6						
L.B.	RH	21	36	>11	25	32	35	3	−1	≫9:6
	LH		35	>11		30	36	6	1	≫9:6
	BI		36	>11						
R.S.	RH	15	18	8:0	–	–	–	–	–	–
D.W.	LH	18	21	8:9	21:3	18	23	5	2	9:6

TABLE III

Age and IQ Estimates (From Raven, 1960, 1965; Burke, 1972) Based on Unilateral and Bilateral Scores on Raven's Standard Progressive Matrices

		RSPM					Actual WAIS IQ		
Patient	Hemisphere	Raw score (max=60)	Age estimate	Percentile ranks Raven	Percentile ranks Burke	Estimated postop. WAIS IQ	Postop.	Preop.	Measure used
N.G.	RH	16	7:9*	<25	4	74	71	74	WAIS performance scale
	LH	16	7:9*	<25	4	74	83	79	WAIS verbal scale
	BI	19	8: 2**	<25	8	78	77	76	WAIS full scale
L.B.	RH	36	11: 3**	≦25	32	93	100	108	WAIS performance scale
	LH	45	>14:0	≧50	59	103	110	119	WAIS verbal scale
	BI	50	>14:0	≧75	78	111	106	113	WAIS full scale
R.S.	RH	17	7: 10*	<5***	5	75	55	100	Kuhlman-Anderson at age 8
D.W.	LH	19	8: 2**	<5***	7	78	80	125	Stanford-Binet at age 3:6
Means	RH	23	8: 10***	5	13	83	75	94	Composite
	LH	26.7	9: 4***	9***	18	87	91	108	Composite

Free vision scores on the WAIS verbal and performance scales are matched with right and left hemisphere Raven scores, respectively, for comparison.
* Extrapolated.
** Interpolated.
*** Age approximated by closest entry.

sphere advantage in L.B. ($chi^2 = 2.43$, $p > .05$, d.f. = 1, after correcting for continuity) and equal ability in both hemispheres of N.G. (Table III). Table III shows the estimated equivalent WAIS IQ (Burke, 1972), age estimates and percentile ranks for all patients (relative to the normative group with similar ages; Raven, 1960) based on these scores.

The difference in raw scores between the two hemispherectomy cases may not reflect left hemisphere superiority but simply the fact that D.W. was older than R.S. when tested or that he was more intelligent even before the onset of disease. There is a well-documented, positive correlation between Raven score and subject's age (Raven, 1960, 1965) and, indeed, when age is taken into account, both hemispherectomy patients obtain rather comparable percentile ranks relative to their respective age groups: 5th percentile rank for R.S. with left hemispherectomy and 7th percentile rank for D.W. with right hemispherectomy (Table III). This may actually reflect an unexpected right hemisphere competence if the premorbid IQ differences between R.S. and D.W. are at all significant

It is noteworthy that free vision scores of the commissurotomy patients tend to be either equal to unilateral left hemisphere scores — even when the left was inferior to the right as in N.G. (Table II) — or slightly above it (Table III). In those cases where a hemispheric difference exists (N.G. on RCPM and L.B. on RSPM), performance in bilateral vision was usually closer to right-visual-field (left hemisphere) ability than to left-visual-field (right hemisphere) ability. This is an example of the prevailing left hemisphere dominance and of possible interhemispheric effects in the split brain under unrestricted conditions (Zaidel, 1973).

By and large, however, the Raven Matrices reveal a striking absence of consistent laterality effects.

Book vs. Board Form

Table II reveals that N.G.'s two hemispheres are not equally able to benefit from the opportunity for self-correction through overt trial-and-error: the final score of the right hemisphere on the board form of RCPM is equal to that obtained on the book form several years previously. The left hemisphere, on the other hand, has benefitted substantially from error correction so that it now surpasses the right hemisphere. Again, though very small, the laterality effect in L.B. was repeated reliably. The asymmetry cannot be attributed simply to failure by the right hemisphere to take advantage of trial and error: Both hemispheres perform significantly poorer on first attempt than on final solutions of the board form. But the left hemisphere gains more than the right relative to the book form from the sequence of attempts. The fact that the first attempts by both hemispheres in the trial and error sequence are considerably inferior to their respective scores on the book form and on the final solution to the board form shows that both have adopted a changed strategy (check partial solutions). But the right hemisphere, while apparently attracted to close alternatives to the correct item, is unable to use the discrepancy in order to improve its characterization of the desired answer. This pattern echoes that observed for both N.G. and L.B. on some subtests of the ITPA (Zaidel, 1979b).

The conclusion that the book form of the RCPM favors the right hemisphere and that the board form of the test favors left hemisphere strategy is in accord with a study of thirty-two 7-8 year-old children Carlson, Goldman, Bollinger and Wiedle, 1974) in which it was found that verbalization of strategy during and after solution of the problem improved scores in the board form of the test but actually decreased scores in the standard book form.

Unilateral Neglect of Space?

Does either hemisphere show unilateral neglect of ipsilateral space, or a preference for response alternatives in contralateral space? Piercy and Smith (1962), Gainotti (1968), Costa et al. (1969) and Basso et al. (1973) all found a higher incidence of preferences for response positions on the side ipsilateral to the lesion in patients with right as against left cerebral damage and a consequently poorer RCPM performance. Table IV presents an analysis of side preferences in unilateral responses by the disconnected and isolated hemispheres to RCPM and RSPM problems. In general, there is no consistent and significant neglect of ipsilateral visual space in unilateral presentations, i.e., there is no preference for response alternatives on that side of the page which is contralateral to the working hemisphere. The only case of significant neglect occurred in R.S. who had undergone dominant hemispherectomy and who tended to point to response alternatives on the left side of the page (Table IV). However, in her case the symptom may be the consequence of a circumscribed parietal-occipital lesion due to installment and revision of a shunt in the remaining right hemisphere. The same lesion may also be responsible for the general and unexpected parietal syndrome which is apparent in this patient (Zaidel, 1973; see also test scores in Gott, 1973).

The result on the other patients confirms a previous report (Zaidel, 1973) and highlights again the difference between the functional competence of a disconnected or isolated hemisphere and that of a patient with a circumscribed lesion in the contralateral hemisphere: Unilateral cognitive competence following cerebral commissurotomy and hemispherectomy is free of some of the focal deficits, such as unilateral neglect of contralateral space following right-brain-damage, which are common in free performance with hemispheric lesions.

TABLE IV

Side (Left, Right) Preferences in Unilateral Pointing Responses to RCPM and RSPM Alternatives

	RCPM					
	LVF		RVF		BI	
	L-R	Trend	L-R	Trend	L-R	Trend
N.G.	−2	−	−5	+	+4	−
L.B.	0	0	−2	+	0	0
R.S.	+10*	+				
D.W.			0	0		

	RSPM					
	LVF		RVF		BI	
	L-R	Trend	L-R	Trend	L-R	Trend
N.G.	−4	−	−8	+	−8	+
L.B.	−10	−	−7	+	−4	+
R.S.	+10	+				
D.W.			−1	+		

* Significant beyond the .01 level of confidence (Costa et al., 1969).

In the RCPM the correct solutions are equally distributed on left and right of the page but in the RSPM there are four more correct responses on the left than on the right.

+, 0, and − denote the presence, absence, and reversal, respectively, of a trend to ignore alternatives on the ipsilateral side of the active hemisphere.

Set and Item Analysis

Comparison of unilateral scores on individual problem sets revealed a progressively larger right hemisphere dominance in subsequent sets of RCPM, both in the present administration and in the tactual version (D. Zaidel and Sperry, 1973), but not in the RSPM (Figure 1). The sets common to all three tests, however, show consistent relative hemispheric dominance. This result is supported by a factor analysis of the five problem sets in RSPM (Rimoldi, 1948) when five of the six identified factors which differentiate the problem sets are given an a-priori hemispheric interpretation (Zaidel, 1981).

Error Patterns

Several lines of evidence converge to show qualitatively different patterns of hemispheric errors on RPM problem items, even though mean rank orderings of problem difficulty for the left and right hemispheres in all sets of RCPM and RSPM, except A and A_B, correlate positively and significantly. In addition to shifting hemispheric asymmetries with test (Colored vs. Standard), form (book vs. board), and problem set, as observed above, there is also a sense in which the right hemisphere is less sensitive than the left to item difficulty. The items within each problem set of RPM progress in difficulty from easy to hard and each subsequent problem set is, in turn, increasingly more difficult than its predecessor. In order to assess possible hemispheric differences in reaction to the progression of item difficulty within each problem set, we have computed a laterality measure twice for each set, once for the first ("easy") six problems, and once for the last ("hard") six problems. Table V [(L–R) / (L+R)] shows that there is a larger left hemisphere dominance on the more difficult problems (2nd) in all cases. Yet the laterality indices of the second halves of the problem sets do not increase linearly with progressing sets (which presumably increase in difficulty as well). Let *a* denote a unilateral score on the first half of a given problem set and let *b* denote the unilateral score on the second half of the same set. Then (a–b)/(a+b) is a unilateral difference

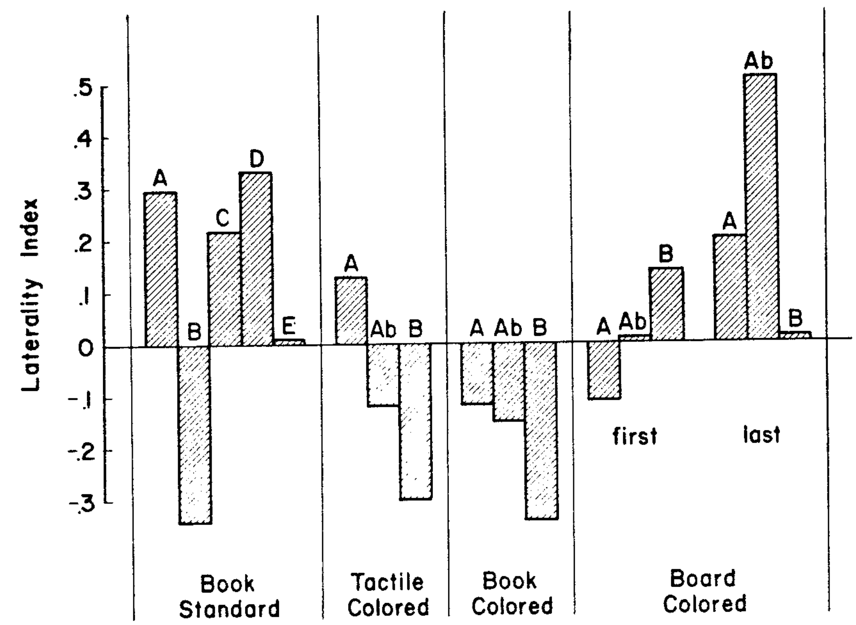

Fig. 1 — *Differences between left and right hemisphere performances on the individual sets in the tactile (D. Zaidel and Sperry, 1973), Colored (RCPM) and Standard (RSPM) versions of Raven's Progressive Matrices, and in the board version of the Colored Matrices. A, A_B, B, C, D, E denote sets of 12 problems each with progressively increasing difficulty. Mean scores for patients N.G. and L.B. are shown. The laterality index is* $f=(L_c-R_c)/(L_c+R_c)$ *if* $L_c+R_c \leq 100\%$ *and* $f=(L_c-R_c)/(L_e+R_e)$ *if* $L_c+R_c > 100\%$. $L_c(L_e)=$ *percentage correct (erroneous) left hemisphere responses.*

measure between "easy" and "hard" problems. Table V also shows [(1–2)/(1+2)] that this difficulty measure increases monotonically with progressing problem sets for the left hemisphere but not for the right hemisphere. This suggests that the right hemisphere is more labile than the left and less likely to be affected by item difficulty. The failure of increasing left hemisphere dominance to occur across sets must be attributed to the erratic right hemisphere scores as a function of progressing set, and suggests that the a-priori selection of set difficulty in designing this test, was biased in favor of left hemisphere criteria.

IQ Estimates

Table III includes estimates of unilateral full scale IQ based on raw scores of RSPM from the equivalency tables of Burke (1972; see also Shaw, 1967, and Peck, 1970). With the exception of the dominant hemispherectomy patient, the predicted IQs based on raw RSPM scores in free vision (BI) are in excellent agreement with the actual full-scale WAIS IQs in free vision so that the unilateral IQ estimates may be regarded with some confidence as well. The greater disparity in IQ scores in R.S. may be attributed, in part, to her right occipito-parietal lesion. It suggests that the WAIS alone is ill equipped to measure right hemisphere function. Furthermore, Table III demonstrates that the common association of scores on the verbal scale of the WAIS with the left hemisphere and of the performance scale with the right is not supported by these data (cf. Klove, 1974).

Discussion

The scores on the Raven Matrices obtained for the right and left hemispheres independently in split brain and hemispherectomy subjects failed to show marked laterality differences. These results, along with those of factor analyses with normal subjects, and studies of patients with unilateral cerebral disease, support the conclusion that the RPM involves abilities and strategies from both hemispheres so that either one can solve a substantial part of the test (cf. also Colonna and Faglioni, 1966; D. Zaidel and Sperry, 1973; Kertesz and McCabe, 1975). Thus, the seeming visuo-spatial and nonverbal character of RPM is misleading and the test is a poor tool for discriminating right and left brain-damaged patients (D. Zaidel and Sperry, 1973) or for assessing lateralized, e.g., visuo-spatial, abilities. Our data show that this is so not because each hemisphere alone is deficient on this test but rather because each is relatively competent on it.

If we take unilateral scores on RPM as measures of general intelligence or problem solving ability, then we may conclude that the problem solving ability of the disconnected or isolated left hemisphere though some-

TABLE V

Comparison of Combined Unilateral RCPM and RSPM Scores on the First Versus the Second Half of Each Problem Set

Problem set	LH scores		RH scores		L–R		(L–R)/(L+R)		1st–2nd		(1–2)/(1+2)	
	1st half	2nd half	1st half	2nd half	1st	2nd	1st	2nd	LH	RH	LH	RH
RCPM												
A	16	13	17	10	–1	3	–.03	.13	3	7	.10	.26
A_B	15	12	16	12	–1	0	–.03	0	3	4	.11	.14
B	13	7	16	8	–3	–1	–.10	–.07	6	8	.30	.33
RSPM												
A	16	12	17	7	–1	5	–.03	.42	4	10	.14	.42
B	11	7	17	8	–6	–1	–.21	–.07	4	9	.22	.36
C	11	5	9	4	2	1	.10	.11	6	5	.23	.38
D	9	3	5	0	4	3	.29	1.0	6	5	.50	1.0
E	5	1	5	0	0	1	0	1.0	4	5	.67	1.0

(L–R) / (L+R) is a laterality measure for each half set. (1–2) / (1 + 2) is a difficulty difference measure for each hemisphere on a given set.

what superior to the right is fairly equivalent to it, and that the left hemisphere, in turn, approximates the problem solving ability of the brain as a whole – split or intact. (It may nonetheless be true that particularly high creativity and intelligence depend critically on interhemispheric interaction (Bogen, 1975), so that disconnection could then result in a significant drop of unilateral "intelligence" relative to the whole, intact brain). To the extent that RPM represents "g", as held by Spearman (1946) and others (Vernon, 1961), but no other left-right asymmetrical factors, our data suggest that the two hemispheres are comparable (similar in total competence) but not quite equipotential (exhibiting qualitatively different patterns of performance) with respect to "general intelligence".

Spearman himself (1946) noted two strategies for solving Raven Progressive Matrices problems: an "analytic" strategy which consists of sampling one element at a time and a "synthetic" strategy in which the patterns are grouped into larger units or wholes. Intuitively, this would seem to foreshadow left versus right hemisphere information processing. Spearman (1946) also contended that only the analytic strategy and not the synthetic one tends to load neogenetic processes with "g", which would point to a left hemisphere dominance on the RPM. Actually, Spearman regarded "g" as equally distributed throughout the cortex. Since the RSPM has more items which are analytic and difficult than does the RCPM, it would follow from the scores that the left hemisphere tends to be superior in "g". "g" is then neither homogeneously distributed in the cerebral cortex nor does it follow the mass action principle in the brain as a whole.

However, the qualitatively different error patterns of the two hemispheres, their different sensitivity to specific items and problems sets, and their different reaction to errors, all suggest that two distinct subspecies of "g" may need to be distinguished, i.e., g_L and g_R. Cattell has made a similar proposal (e.g., 1971) that "g" be split into two broad or general ability factors, fluid intelligence, "g_f", and crystalized intelligence, or "g_c". The latter is said to correspond in content to many traditional IQ tests with heavy loadings on the primaries of "verbal ability", "numerical ability" and "reasoning". It operates in areas where judgment has been taught systematically or experienced before. Fluid intelligence (g_f), on the other hand, operates where the sheer perception of complex relations is involved and where stored experience is irrelevant. Although it is tempting to associate g_f with the right hemisphere and g_c with the left, this interpretation does not withstand closer scrutiny (Zaidel, 1979a). Rather than interpret existing intelligence factors in hemispheric terms it seems more fruitful to redefine at least two of the main factors in any theory by tests that are hemispherically as pure as possible (cf. Bogen, 1975).

The assumption by the British school that RPM is a pure test of "g" to the exclusion of other lateralized factors is warranted neither by the foregoing data nor by extensive factor analyses of the test (Rimoldi, 1948; Burke, 1958). Our data indicate that the Colored and Standard Progressive Matrices do involve left-right asymmetrical intellectual factors, and that in fact the two tests have neither equal nor uniform loadings on these factors. Figure 1 illustrates nonuniformity within the tests, and the discrepancy between the age scores of either hemisphere of the same patient on the two RPM tests, especially in the case of N.G. (Tables II and III), illustrates nonuniformity across the tests.

The board form of the RCPM effected illuminating changes of strategy in both hemispheres. When they were encouraged to try out alternative solutions overtly, both hemispheres made many more errors in their first choices than they did on the book form. But the left hemisphere of patient N.G. proved to be much better at error correction than the right. (L.B. showed a ceiling effect.) It is as if the right hemisphere is a poor judge of degree of correctness among close alternatives, as if its solution strategy is not constructive, in the sense that it yields no retrievable information about partial solutions. We may say that the right hemisphere has an incomplete model of its own information processing (Zaidel, 1978).

Did the patient's error correction strategies reveal interesting hemispheric asymmetries? Commissurotomy patient N.G. often rotated the chip which she had placed in the empty space on the board in an attempt to get a better "perceptual" fit. This may be regarded as a Gestalt strategy. N.G.'s right hemisphere used it 16 times in 7 different problems whereas her left hemisphere tried it only 8 times in 4 problems. The correct pattern (though incorrect solution, of course, as the patient always realized herself) resulted in 5 (=31%) rotations attempted by the right hemisphere but in only 1 (=13%) by the left. And yet three of those rotations by the right hemisphere which completed the problem correctly (though placed inappropriately) did not lead eventually to correct solutions of the problems. The one such rotation by the left hemisphere did eventually lead to a correct solution. Thus, the right hemisphere indeed tends to adopt a different overt error correction strategy than the left.

The results of trial and errors on the board form of the RCPM are consistent with the hemispheric asymmetry in error correction noted in a study of unilateral performances on the Visual Reception and Visual Association subtests of the Illinois Test of Psycholinguistic Abilities (Zaidel, 1979). In those standard tests each hemisphere had to select, by pointing, one picture out of four which best related to a stimulus picture or completed a visual analogy problem. However, each hemisphere was allowed a second try in case of an error. The results showed that when guessing was taken into account, only the left hemisphere showed a significant improvement due to error correction. Here, too, the left hemisphere seemed better able to evaluate alternative solutions under uncertainly.

The Raven Matrices illustrate the similarities and differences between the disconnected or isolated hemispheres and patients with unilateral cerebral insult. The performance of the patient with a lesioned hemisphere reflects the net effect of residual structures in the diseased hemisphere, compensatory process in the undamaged hemisphere, and a repressive influence, in the presence of the commissures, that disruption of function by lesion in one hemisphere has on related functions in the undamaged hemisphere (Sperry et al., 1969). Comparison with the split brain can tease apart true compensatory processes from pathologically inhibited functioning in the undamaged hemisphere. Thus, in the case of the RPM, the right hemisphere of a patient who had undergone brain-bisection or hemidecortication may show a different sensitivity to item difficulty than does a patient with left cerebral insult (cf. Knehr, 1956; Urmer, Morris and Wendland, 1960). Neither does the single left hemisphere exhibit the focal behavioral deficits, such as unilateral neglect of contralateral space, which are often associated with right parietal insult. Thus, unilateral neglect is a consequence of pathological influence by a right hemisphere lesion rather than of residual left hemisphere competence.

By the same token, the variable laterality indices on different problem sets observed in the disconnected and isolated hemispheres can be reflected in more subtle laterality effects with hemispherically damaged patients. Thus, Denes et al. (1979) found that two groups of left and right brain-damaged patients matched for severity of lesion and tested in the acute stage on a version of the RCPM designed to minimize the effects of unilateral neglect of space, did not differ in overall scores. However, a retest two months later showed selective improvement by the right brain-damaged patients on set B. This is just what our data predict (Figure 1). It would follow that this laterality effect observed following hemispheric damage, in contrast to unilateral neglect, reflects the positive competence of the residual hemisphere.

Abstract

Each hemisphere of two commissurotomy and two hemispherectomy patients was tested separately on the book form of Raven's Standard Progressive Matrice test (RSPM) and on the book, board and tactile forms of Raven's Coloured Progressive Matrices test (RCPM). The two patients who had undergone complete cerebral commissurotomy were tested unilaterally with the aid of a contact lens technique which permits free unilateral ocular scanning and visual guidance. The two other patients had undergone dominant (right) and non-dominant (left) hemispherectomy for post-infantile lesions and were tested in free

vision. IQ estimates for the left hemispheres based on RSPM scores ranged from 74 to 103 (mean 87) and right hemisphere IQ estimates ranged from 74 to 93 (mean 83).

Whereas a small and insignificant trend for left hemisphere dominance was observed on the RSPM, an insignificant trend of right hemisphere superiority appeared on the RCPM. The same trend of right hemisphere advantage had been observed on a tactile-visual modification of the RCPM (D. Zaidel and Sperry, 1973). Thus, the suggested laterality pattern seems to be modality non-specific. In contrast to the small difference in lateral preference for each of the two tests as a whole, the individual problem sets in both tests yielded different laterality indices. Further, bigger laterality effects were observed on more difficult items. The right hemispheres also seemed more labile and less sensitive to item difficulty than either the corresponding left hemispheres or normal subjects with comparable scores.

Instructions to use an overt trial-and-error solution method with the board form of the RCPM resulted in a change of strategy in both hemispheres. But only the left hemisphere of patient N.G., who did not have a ceiling effect, seemed to benefit from the opportunity for error correction to become superior on this version of the RCPM. The right hemisphere seems unable to utilize partial information as if its solution strategy is non-constructive.

Neither the isolated nor the disconnected hemisphere has the dramatic focal deficits, such as unilateral neglect of space or dramatically reduced RPM scores, which often accompany unilateral cerebral insult.

To the extent that RSPM measures general intelligence ("g"), our data suggest that "g" is bilaterally represented though in unequal amounts for different parts of the test. Thus, the data better support the primary abilities model of intelligence with localized and neurologically dissociable cerebral organization, than they support a hierarchical model incorporating a concept of "g" that enters into all intellectual functions and is homogeneously represented in the cerebral cortex. It is suggested that "g" may contain at least two independent factors, g_L and g_R.

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