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DIASCHISIS, SITE, TIME AND OTHER FACTORS IN RAVEN PERFORMANCES OF ADULTS WITH FOCAL CEREBRAL LESIONS

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Analyses of Raven matrices performances by 35 patients with acute and 22 with chronic focal lesions restricted to the anterior or posterior regions of the left or right hemispheres illustrate the importance of controlling for diaschisis, specific site, time, age and other factors determining neuropsychological performances. These findings have important practical and theoretical implications with respect to the elucidation of principles underlying organization, disorganization and reorganization of human brain functions. They also suggest that many of the previous controversial and conflicting reports may be reconciled when these and other significant underlying factors are accounted for. Finally, they confirm Jackson's earlier observations of the critical role of the right posterior lobe in "visuopsychic" non verbal mental processes.

Keywords: diaschisis, Raven Matrices, brain tumors, focal cerebral lesions, age, brain lesion dynamics, neuropsychological performance

"The tendency to appear exact by disregarding the complexity of factors is an old failing in our medical history."

J. H. Jackson, 1915, p. 112

The Raven Standard Progressive Matrices (RPM) and the Raven Coloured Progressive Matrices (RCM) were developed as "nonverbal" tests designed to measure "the capacity to form comparisons and reason by analogy" (Raven, 1952, 1965, 1975). Spearman (1964) described the matrices as "perhaps the best of all non-verbal tests."

As with the Weschsler scales and other psychological tests designed to measure various cerebral functions, beginning with Knehr (1956), subsequent studies reported that the matrices differentiated patients with diverse brain lesions from those with affective disorders and normals (Costa & Vaughan, 1962; Dils, 1960; Evans & Marmorston, 1964; Knehr, 1965; Urmer, Morris & Wendland, 1960).

Factors Affecting Raven Performances

Attempts to "localize" the specific nonverbal cognitive functions tapped by the Raven Matrices or the specific locus of lesion affecting Raven performances however, have yielded controversial findings. Some studies reported poorest

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performances by patients with right hemisphere lesions (Costa, Vaughan, Horowitz & Ritter, 1969; Costa, 1976; Gainotti, Caltagirone & Miceli, 1977; McFie, Piercy & Zangwill, 1950; Piercy & Smyth, 1962). Others found no differences in Raven performances as a function of lateralization (Archibald, Wepman & Jones, 1967; Basso, DeRenzi, Faglioni, Scotti & Spinnler, 1973; Denes, Carlo, Stoppa & Gradenigo, 1978; DeRenzi & Faglioni, 1965; Meyer & Jones, 1957). Still others (Arrigoni & DeRenzi, 1964) reported that rather than locus, "severity" of lesion (based on visual reaction time) was the most significant factor determining Raven performance. Citing this report, Kinsbourne (1974) attributed poorest Raven performance in older patients to more diffuse and extensive cerebral damage, and described the Raven Matrices as "a first approximation to a behavioral index of diffuse damage."

Based on studies of 2 patients with hemispherectomy and 2 patients with commissurotomy, Zaidel, Zaidel and Sperry (1981) reported "bihemispheric competence" for the Raven Matrices, or that either the left or right hemispheres alone could perform adequately on the Raven Tests.

Studies of associations of poor Raven scores with other defects, including visual neglect, constructional dyspraxia and aphasia have also been controversial.

Visual field defects (either right or left) have been reported to be associated with poor Raven scores. Colombo, DeRenzi and Faglioni (1976) and Costa et al. (1969) reported that such patients commonly showed systematic neglect for answers on the side of the page contralateral to the lesion. According to Costa et al. (1969) and Gainotti et al. (1977) neglect was most frequent in patients with right posterior lesions. In a study controlled for visual field defects, Piercy et al. (1962) presented evidence that visual field defects alone could not explain poorest Raven scores by patients with right-sided lesions.

Comparisons of Raven performances in aphasic and nonaphasic patients have also reported controversial findings. Although Arrigoni et al. (1964) and DeRenzi et al. (1965) concluded that presence of aphasia does not affect Raven performances, Colonna and Faglioni (1966) and Basso et al. (1973) reported poorer Raven scores by aphasics than nonaphasics. Still others have reported that the effect of aphasia on Raven performance varies as a function of the type of aphasia. Archibald et al. (1967) noted that some global aphasics performed better on the RCM than patients with less severe aphasia. Costa et al. (1969) reported poorest Raven scores by "mixed" and "receptive" aphasics. Similarly, Kertesz and McCabe (1975) claimed that Broca's aphasics performed better than aphasics with less severe expressive deficits and that aphasics with comprehension deficits showed poorest performances. Zangwill (1964) described RPM scores among motor aphasics as "adequate," unless the aphasia was associated with constructional dyspraxia.

Other studies have reported systematic associations of poor Raven scores with constructional dyspraxia (Costa et al., 1969 and Piercy et al., 1962). These findings suggest that one or more of the nonverbal receptive, perceptual and/or mediation processes underlying Raven Matrices performance may also be critical to visual constructional tasks.

As with many other tests of cognitive functions, recent studies have increasingly indicated the significance of extracranial factors in Raven performances. For example, numerous studies have reported poorer Raven scores for those with lower than higher education levels and /or lower than higher socioeconomic status (Bartlett, Newbrough & Tulkin, 1972; Berker, Lorber & Smith, 1983; Eisenthal & Harford, 1971; Hsu, 1976; Tulkin & Newbrough, 1968).

Factors Underlying Effects of Cerebral Lesions

Beginning in 1962, Smith has repeatedly called attention to unwarranted assumptions, inherent ambiguities and methodological errors in neuropsychological studies of patients with diverse brain lesions (1962, 1975, 1981). He pointed out that the effects of "brain damage" vary according to specific factors, including age, socioeconomic status, education, site, nature of the lesion (intrinsic versus extrinsic, evolving versus resolving, etc.), status of the presumed healthy hemisphere (i.e., diaschisis or "distance effects") "momentum" of the lesion, and nature of the tests used. Smith also called attention to the accumulated evidence supporting Jacksonian principles underlying the organization and development of brain functions and their disorganization and reorganization following brain insults at different stages of cerebral maturation. He suggested that many of the paradoxical and seemingly contradictory findings that have characterized the literature may be reconciled when these Jacksonian principles, the various factors, and tacit unwarranted assumptions in previous studies are taken into account (Smith, 1984).

For example, comparisons of groups with lateralized lesions tacitly assume a functional equipotentiality of anterior and posterior regions within each hemisphere (Smith 1966a, 1966b, 1975, 1979, 1981). However, numerous earlier studies have reported consistent differences in effects of anterior and posterior lesions in both the right and left hemispheres. Moreover, combining patients with heterogeneous lesions tested at different stages in the course of the underlying neuropathological process assumes that the effects do not vary as a function of their nature (e.g., intrinsic versus extrinsic, acute versus chronic, and resolving versus evolving, rapid versus slow onset, discharging versus nonepileptogenic) or changes in their effects with time. For example, previous studies of patients with evolving lesions tested serially have systematically demonstrated consistent progressive declines in Raven scores (Smith, 1981). In contrast, serial studies of patients with resolving lesions showed systematic gains with time (Culton, 1969; Smith, 1981; Denes et al., 1978; Kertesz, 1979).

Studies of patients with left- versus right-sided lesions also tacitly assume that functions of the anatomically normal opposite hemisphere are intact and immune from disruption by pathological effects radiating from the damaged hemisphere. The importance of such "distance effects" in determining the sequelae of cerebral lesions was first emphasized by von Monakow (1914) who described the phenomena of radiating pathological influences as diaschisis.

Von Monakow observed that while the effects of diaschisis were characteristically transitory, they could also last indefinitely and sometimes be permanent. Numerous recent studies demonstrating bilateral attenuation of cerebral metabolism and regional blood flow in subjects with unilateral lesions are strikingly consistent with von Monakow's findings (Endo, Larsen & Lassen, 1977; Ginsberg, Reivich, Giandomenico & Greenberg, 1977; Kuroda, Olsen & Lassen, 1982; Lavy, Melamed & Portnoy, 1977; Lenzi, Frackowiak & Jones, 1982; Meyer, Shinohara, Knada, Fukouchi, Ericsson & Kok, 1970; Reivich, Jones, Castano, Crowe, Ginsberg, & Greenberg, 1977; Skinhoj, 1965; also see Smith, 1981, 1983, 1984).

Analysis of neuropsychological performances in a selected population of patients with neurosurgically verified focal lateralized lesions tested in the "acute" and later postoperative or "chronic" stages afforded bases for evaluating the significance of time, site, diaschisis, age and other factors determining Raven Matrices performances.

PATIENTS AND METHODS

In contrast to most previous studies in which cases with acute and chronic focal cerebral lesions were combined as a presumably homogeneous population of "brain damaged" patients with "lateralized lesions," 72 Veterans' Administration patients with verified focal resectable lesions were screened and differentiated according to specific site and time of testing relative to onset.

To evaluate the significance of specific site of lesion as a factor affecting RCM performance, only patients with lateralized lesions restricted to either the anterior (prerolandic) or posterior (postrolandic) regions of the left or right hemispheres were included in this study. Patients with lateralized lesions overlapping the rolandic fissure and others with bilateral cerebral lesions were excluded.

To evaluate the significance of time, or the condition of the brain as a factor of time, this selected population was further differentiated into subgroups examined during the "acute" (preoperative or early postoperative) stages versus those tested in the "chronic" (later postoperative) stages as described below.

The Raven coloured Progressive Matrices (RCM) (Raven, 1965), Purdue Pegboard (Costa, Vaughan, Levita & Farber, 1963) and the Single and Double Simultaneous Stimulation Test (DSS) (Centofanti & Smith, 1979) were included in examinations of all patients tested in the acute and/or chronic stages.

RAVEN PERFORMANCES OF PATIENTS WITH ACUTE FOCAL LESIONS

Of 72 patients 35 met the criteria for specific site of the lesion and had been tested in the acute stage; i.e., 25 patients were tested within 14 days before (mean 3.5 days) and 10 patients were tested within 20 (mean 13.6 days) after neurosurgery. As expected for samples drawn from VA populations, the 35 patients included only one female. The mean age for the group was 43.9 years (range, 25 to 65 years) and their mean education was 11.3 years (range 3 to 17 years). Two patients were left-handed. Of the 19 patients with acute right and 16 with acute left hemisphere lesions, 3 were aphasic, all with left posterior lesions; 2 patients had right homonymous hemianopia, 2 patients had left homonymous hemianopia, and 1 patient had left inferior quadrantanopia, with corresponding lesions in the posterior regions of the contralateral hemisphere.

The nature and locus of the lesions were verified at neurosurgery and consisted of 12 gliomas, 6 meningiomas, 4 aneurysms, 3 arteriovenous malformations, 3 angiomas, 2 metastatic tumors, 2 astrocytomas, 1 abscess and 2 unclassified tumors. Despite apparent differences in the ultimate consequences of malignant evolving and nonmalignant resolving lesions in patients tested both pre- and postoperatively, analysis of the data revealed no systematic effect of type of lesion or time of testing (in patients tested shortly before or after surgery) on Raven performances in the acute stage.

As in many previous studies comparing groups with right versus left hemisphere lesions, analysis of variance revealed no significant differences in mean RCM score, age or education between the 16 patients with left and the 19 patients with right sided lesions (Table 1). However, as noted above, such comparisons failed to take into account the reported differences between the effects of anterior versus posterior lesions within the right hemisphere on nonverbal cognitive abilities. The critical importance of this specific site factor is illustrated in Table 2.

TABLE 1
Comparisons of patients with acute left versus right hemispheric lesions

Site	RCM	Age	ED
Right lesion ($N = 19$)	21.8	45.3	11.7
Left lesion ($N = 16$)	24.1	42.3	10.7

Table 2 presents further comparisons using ANOVA with Sheffé allowances of the component subgroups consisting of 12 right posterior, 7 right anterior, 7 left anterior, and 9 left posterior lesion patients. Differences in mean age and education between the four subgroups were nonsignificant. However, in contrast to the absence of significant differences between RCM performances of the 16 patients with left- (24.1) versus the 19 with acute right-sided lesions (21.8), the mean RCM score for the right posterior group (17.0) was markedly subnormal and significantly poorer than normal scores for the right anterior (30.0; $p < .0001$) and left anterior (27.9; $p < .001$) groups (Table 2).

TABLE 2
Comparisons of RCM, age and education by site in the acute stage

Site	RCM	Age	ED
Right posterior ($N = 12$)	17.0	46.8	11.3
Right anterior ($N = 7$)	30.0	42.7	12.7
Left anterior ($N = 7$)	27.9	37.0	11.3
Left posterior ($N = 9$)	21.2	46.3	10.3

RP versus RA ($p < .0001$); RP versus LA ($p < .001$).

The critical importance of differentiating intrahemispheric locus of lesion is clearly demonstrated by the marked contrast between the normal RCM mean score for the right anterior group and the profoundly subnormal mean score for the right posterior group.

The difference between the mean Raven scores for the right posterior group (17.0), and the left posterior group (21.2) was not significant. These findings can be interpreted as evidence supporting earlier reports that both posterior lobes, but not the anterior lobes, play a critical role in Raven performances. The findings also suggest bihemispheric vulnerability and/or competence for the RCM. However these differences were recorded during performances of the *acute* stage.

In addition to the obvious importance of controlling for the specific locus of lateralized lesions in studies of selected patients tested in the acute stage, comparisons of Purdue Pegboard and DSS performances illustrated the necessity of controlling for still another factor. As noted above, only patients with neurosurgical verification of lesions restricted to either the right or left hemisphere were included in this study. Yet, although all 35 patients tested in the acute stage had surgically verified *lateralized* lesions, 19 (54.3%) showed *bilateral* motor deficits.

Reports by von Monakow and Mourgue (1928), that the frequency and severity of diaschisis are greater in older than younger patients have been supported by more recent studies (Smith, 1983). In our sample of patients with verified lesions

restricted to one hemisphere, all six oldest patients (range: 57 to 65 years old) demonstrated bilateral sensory and/or motor deficits. By contrast, only two of the six youngest patients (range: 25 to 30 years old) showed bilateral involvement. Bilateral motor deficits were most frequent in patients with posterior malignant tumors. However, in contrast to bilateral deficits in all 5 older patients with posterior malignant tumors, only 1 of 3 younger patients with like tumors showed bilateral sensory and/or motor deficits.

Consistent with reports of numerous earlier studies, our findings reveal poor RCM performances in patients with left as well as right posterior lesions in the acute stage. However, unlike other previous reports, inclusion of the Purdue Pegboard provided bases for assessing the status of the presumed normal hemisphere contralateral to the lesions. Previous comparisons of patients with right- versus left-sided lesions tacitly assumed the hemisphere contralateral to the lesion to be intact. Findings of a high incidence of *bilateral* sensory and motor deficits in our sample of patients with acute focal lesions are consistent with our previous studies of patients with hemispherectomy, commissurotomy, vascular and other types of lateralized lesions, and indicate that this tacit assumption is unwarranted. For example, of the 15 patients with the poorest RCM scores (below 22) 14 (93.3%) showed bilateral sensory and/or motor deficits, indicating pathological involvement of *both* hemispheres. Thus, although numerous studies have reported poor Raven scores by patients with lesions presumably restricted to either the left or right hemisphere, conclusions that mechanisms in both hemispheres are critical to RCM performances are clearly questionable.

RAVEN PERFORMANCES OF PATIENTS WITH CHRONIC FOCAL LESIONS

Examination of patients in the chronic stage afforded data for evaluation of von Monakow's characterization of the effects of diaschisis as usually transitory. Follow-up studies of patients after the acute stages (with diminution of the effects of diaschisis) also afforded bases for more precise identification of lateralized cerebral mechanisms involved in RCM performances. For purposes of this study, patients with examinations at least 1.5 (and up to 16) months postneurosurgery were included in the chronic group.

Of the 72 patients, 22 met the following criteria: (1) neuropsychological examinations not less than 1.5 months after surgical resections (range 1.5 to 16 months), and (2) patients with focal lesions restricted to the pre- or postrolandic area of the left or right hemispheres. The resulting sample consisted of 7 patients with left posterior, 6 with right posterior, 7 with left anterior, and 2 with right anterior lesions. The lesions consisted of 5 gliomas, 5 arteriovenous malformations, 3 meningiomas, 3 astrocytomas, 2 abscesses, 2 angiomas, and 2 aneurysms. The mean postoperative testing interval was 6.7 months, ranging from 4.5 for the right anterior group to 7.2 months for the right posterior group. All patients were males, mean age 40.8 years (range, 21 to 66 years) and mean education 11.3 years (range, 6 to 18 years). One patient was left handed. Three patients were aphasic, all with left posterior lesions; 1 patient had a right homonymous hemianopia and 1 a left homonymous hemianopia.

Similar to comparisons of the four subgroups with acute lesions, differences in age and education were nonsignificant. However, in contrast to marked and statistically significant differences in RCM performances between selected

subgroups in the acute stage, none of the differences between the four subgroups in the chronic stage was significant. (Table 3: ANOVA, with Sheffé allowances).

TABLE 3
Comparisons of RCM, age and education by site in the chronic stage

Site	RCM	Age	ED
Right posterior ($N=6$)	26.0	47.5	10.5
Right anterior ($N=2$)	30.0	43.5	13.0
Left anterior ($N=7$)	30.6	38.4	11.1
Left posterior ($N=7$)	31.9	36.7	12.6

Associated Changes in Sensory-Motor Function

Comparisons of Purdue Pegboard and DSS performances revealed a striking decrease (over 50%) in the indicence of bilateral sensory and motor deficits from the acute to the chronic stage (Table 4). These changes might be attributed to group differences between those meeting criteria for inclusion in acute versus chronic subgroups. However, 17 of the 22 were also tested during the acute stage. Comparisons of Purdue Pegboard and DSS performances for the 17 patients in the acute and chronic stages with the total sample of 35 acute and 22 chronic patients showed comparable striking declines in the incidence of bilateral deficits (both over 50%, Table 4).

TABLE 4
Incidence of bilateral motor deficits in the acute and chronic stages

	Acute stage			Chronic		
	N	RPM score	% Bilateral motor deficit	N	RPM score	% Bilateral motor deficit
17 patients tested pre and post	17	19.6	41.2	17	27.3	17.4
35 acutes and 22 chronics	35	16.7	54.3	22	27.6	22.7

Thus, the decrease in incidence and severity of bilateral motor deficits *cannot* be readily attributed to sample selection. Instead, the decrease is consistent with von Monakow's findings of changing effects of diaschisis in different types of evolving and resolving lesions with time. The significance of the marked decline in the incidence of bilateral cerebral dysfunction from the acute to the chronic stage is strikingly illustrated by changes in correlations of right and left hand Purdue Pegboard performances. In the acute stage, correlations between RCM scores and right ($r=0.56$, $p<.01$) and left hand ($r=0.65$, $p<.01$) Purdue Pegboard performances were significant. In the chronic stage, the correlation between the RCM score and the Purdue Pegboard left hand performance remained significant ($r=0.68$, $p<.01$). However, the significant correlation between the RCM score and the Purdue Pegboard right hand observed in the acute stage vanished. The lack of a

significant correlation between the RCM and Purdue Pegboard right hand score in the chronic stage indicates a selective association of RCM performance and right hemisphere function. We propose that this selective association was obscured in the acute stage due to more widespread effects of the lateralized lesions, but emerged in the chronic stage with diminution of diaschisis. Also consistent with diminution of diaschisis is the marked improvement in RCM scores from the acute to chronic stages (Table 5).

TABLE 5
Correlations of Purdue Pegboard and Raven Matrices scores in the acute and chronic stages

	Acutes ($N=35$)		Chronics ($N=22$)	
	RCM	Right pegs	RCM	Right pegs
Left pegs	0.65**	0.70**	0.68**	0.35
Right pegs	0.56**	—	0.18	—

**$p<.01$.

Differential Vulnerability of Efferent versus Afferent Functions

Jackson (1915) emphasized that the vulnerability of brain functions to the effects of brain damage differs according to the nature of the function. He observed that deficits in efferent voluntary motor functions were more frequent and severe than deficits in afferent involuntary or automatic functions. He described this principle as the "law of destroying lesions."

Our findings are strikingly consistent with Jackson's conclusions which were based solely on his brilliant clinical observations over 100 years ago. As Table 6 shows, unilateral and bilateral impairment in efferent motor function on the Purdue Pegboard test occurred far more frequently than like impairment of afferent somatosensory function tapped by the Single and Double Simultaneous Stimulation Test.

TABLE 6
Incidence of sensory* versus motor deficits in the acute and chronic stages

	Acute ($N=35$)			Chronic ($N=22$)		
	N	%	RCM	N	%	RCM
Bilateral motor	19	54.3	16.7	5	22.7	27.6
Unilateral motor	11	31.4	29.1	12	54.6	29.9
Normal motor	5	14.3	28.8	5	22.7	31.7
Bilateral sensory	2	6.1	16.0	1	4.5	29.0
Unilateral sensory	6	18.2	16.3	2	9.0	26.0
Normal sensory	25	75.8	25.0	19	86.5	30.1

*DSS tests were not obtained in 2 of the 35 acute cases.

For example, only 6.1% of the cases showed bilateral sensory deficits in the acute stage in contrast to 54.3% with bilateral motor deficits. The greater vulnerability of the efferent motor than afferent sensory functions to brain insults has been consistently reported in studies of other populations including congenital

hydrocephalus (Berker, 1985), Cushing's disease (Whelan, Schteingart, Starkman, & Smith, 1980), hemispherectomy, commissurotomy, traumatic, vascular and other lateralized and bilateral cerebral lesions (Smith, 1981).

DISCUSSION

Before considering the findings of this study, it is important to emphasize specific limitations that qualify any firm conclusions. First, in addition to the highly selective nature of the clinical material, the number of subjects was small. Comparisons of the 35 patients with acute and 22 with chronic lesions are qualified by the limited number (17 patients) with examinations in both the acute and chronic stages. Furthermore, our definitions of acute and chronic were arbitrary. Temporal changes might well reflect resolution of edema and other pathophysiological reactions to surgical intervention rather than diaschisis or distance effects. Thus for example, the diminishing correlation between the right hand motor function and Raven Matrices performance may reflect independent changes between these two functions or resolution of other pathophysiological postoperative complications rather than diminution of diaschisis. It may also reflect intra-or interhemispheric compensatory mechanisms (Campbell et al., 1981).

Despite these significant limitations, which also apply to many earlier studies, our findings are strikingly consistent with principles of human brain function described by Jackson and von Monakow.

In contrast to the paradoxical and seemingly contradictory findings in previous studies comparing effects of various types of lesions tested in various stages on RCM performances, our findings demonstrate systematic and significant differences as a function of specific locus, time, age and distance effects or diaschisis. Apart from conceivably important methodological and theoretical implications, our findings also indicate that many of the diverse and controversial conclusions that have characterized the literature may be reconciled when these and other specific factors are taken into account. They also afford bases for evaluating the validity of diverse earlier conclusions on the nature of the specific mental functions tapped by the RCM as well as the critical role of specific cerebral structures in the performance of the matrices.

Diaschisis

Though largely ignored for over 70 years, the recent literature reflects a growing recognition of the critical importance of von Monakow's discovery and definition of diaschisis (e.g., Finger & Stein, 1982; Finger & Almli, 1984). As noted above, temporal changes from the acute to chronic stages following surgery may reflect the resolution of earlier pathophysiological alterations. However, the markedly greater incidence of bilateral motor and sensory deficits in the acute than chronic stage, and in older than younger patients, is consistent with von Monakow's observations. The findings also attest to the importance of Purdue Pegboard and other tests of right and left hand motor and somatosensory function in studies of patients with lateralized lesions. Although an obviously crude measure of manual motor functions, the value of the Purdue Pegboard in assessment of the status of the lateralized efferent mechanisms in the two cerebral hemispheres has also been demonstrated in previous studies of patients with diverse types of diffuse and lateralized lesions, as well as hemispherectomies (Smith, 1972a, 1981; Berker, Whelan & Smith, 1982; Berker, 1985).

Costa et al. (1969) also reported significant correlations between Purdue Pegboard and Raven Matrices performances only with the hand contralateral to the lesion in 70 patients tested at *varying stages* in the course of diverse neuropathological processes. They reported that the left hand-RCM correlation for patients with right-sided lesions ($r = 0.73$, $p < .01$) was significantly higher than the right hand-RCM correlation for patients with left-sided lesions ($r = 0.48$, $p < .05$). In our sample, the significant left hand Purdue-RCM correlation observed in the acute stage persisted in the chronic stage ($r = 0.68$, $p < .01$). However, the significant relationship between right hand Purdue performance and RCM score observed in the acute stage vanished in the chronic stage.

The significant correlations between right and left hand motor performance with RCM score in the acute, but not the chronic, stage are consistent with the phenomena of diaschisis as described by von Monakow. They indicate patterns of diminution and frequent disappearance of pathological influences radiating from the lateralized lesions variously disrupting the functions of the anatomically intact opposite hemisphere.

These findings also provide bases for more accurate definition of the lateralization of mechanisms critical to Raven performances. The consistent association of levels of left but not right hand Purdue Pegboard performances with Raven scores indicates that specific right hemisphere mechanisms play a more crucial role than those of the left hemisphere in the specific "visuopsychic" or nonverbal mental functions tapped by the Raven Coloured Matrices. More specifically, our findings of normal RCM performances by patients with right anterior lesions, even in the acute stage, emphasize the critical importance of the "posterior lobe" of the right hemisphere in nonverbal reasoning.

Our findings of striking associations and dissociations between left- and right-sided motor deficits and Raven performances emphasize the critical importance of careful assessments of the status of the anatomically opposite and presumably functionally intact hemisphere in studies of patients with chronic as well as acute lateralized cerebral lesions. Our findings also demonstrate that the tacit assumption in most previous studies was unwarranted and misleading, namely, that the anatomically opposite intact hemisphere is also functionally intact. The fallibility of this assumption can be readily demonstrated in patients with acute lateralized lesions in which the presence of diaschisis is reflected by contralateral functional deficits.

Specific Site

Although long overlooked, over 100 years ago Jackson described the left hemisphere as playing a "leading" role in language. He also introduced the concepts of visual ideational or "visuo-psychic" function. However he specified only the "posterior lobe" of the right hemisphere as "leading" in these functions (1876). Our findings of normal Raven performances by patients with right frontal lesions versus markedly subnormal performances by patients with right posterior lesions are strikingly consistent with Jackson's views. Moreover, our findings indicate that conclusions of studies of Raven performances by patients with left- versus right-sided lesions which do not control for specific locus within the right hemisphere are qualified by unwarranted assumptions of intrahemispheric equipotentiality for nonverbal tasks regardless of anterior-posterior locus.

Kertesz and Dobrowolski (1981) reported no differences in Raven Coloured Progressive Matrices scores as a function of anterior-posterior locus in the right

hemisphere. The strikingly divergent findings may in part reflect differences in the nature of the clinical material. Subjects in the Kertesz et al. study were older (mean age = 63.7) stroke patients, while subjects in our study consisted of younger (mean age = 43.9) patients with focal tumors. Von Monakow pointed out that disruption of function of anatomically intact neural structures in patients with brain lesions was more frequent and severe in older than younger patients. Thus, impairment of Raven performances regardless of the locus of lesion in the right hemisphere in older stroke patients may reflect the reduced reserve capacity of the older brain and its greater vulnerability to diaschisis. Poor Raven scores by the older stroke patients, regardless of anterior-posterior locus of the infarct in the right hemisphere may also reflect widespread cerebral pathology due to progressive cerebrovascular disease often associated with stroke. Furthermore, the rapid momentum of cerebrovascular lesions underlying strokes in older patients (in contrast to slowly developing tumors in younger patients) may result in more widespread pathological effects. Thus, is is not surprising that Kertesz reported poor language scores in patients with right hemisphere strokes. Our findings seemingly contradict those reported by Kertesz. However, analysis of differences between clinical groups reveal that the two studies offer complementary views of the importance of the various factors in determining the dynamics of organization and disorganization of cerebral function. They suggest an explanation for the diverse findings in studies of RCM performances of patients lumped together solely on the basis of left or right hemispheric site of lesion; that is, that the frequency and severity of deficits in RCM performances vary markedly according to the proportions with right anterior versus right posterior lesions, status of the presumed normal hemisphere, age, nature of the underlying pathological process, momentum, presence or absence of diaschisis and condition of the brain as a whole.

Time as a Factor Determining Outcome

Disappearance and reduction of the severe deficits in RCM performances from the acute to the chronic stages, not only in groups with left and right anterior and left posterior, but also right posterior lesions, reflect the dynamic interplay of processes underlying cerebral organization, disorganization and reorganization. These processes are reflected in the varying courses and natural history of different types of evolving and resolving cerebral lesions. They begin with disruptions of function due to local and distance effects in the acute stages, and are often followed in the initial postoperative chronic stages by dimunution of the temporary pathological disruptive influences. Varying degrees of spontaneous, continuing recovery and reorganization or further progressive declines depend on the condition of the brain and the nature of the underlying neuropathological anatomy (Smith, 1984).

Our findings indicate that marked differences in long-term outcomes between patients with malignant versus benign tumors are often obscured in the early chronic stages after surgery. For example all 7 patients with gliomas who were tested both in the acute and initial chronic stages (not more than 16 months postsurgery), showed gains on the Raven Matrices ranging from 2 to 16 points. Of the remaining 10 patients with benign tumors, follow-up testing showed gains in 9 and only 1 patient (with a right anterior aneurysm) with a decline from the acute to the chronic stage (a one point drop in RCM score from 26 to 25).

The systematic and marked differences between the greater freqeuency and severity of impairments in the "higher" cognitive functions tapped by the RCM and of associated impairments in "lower" sensory and/or motor function in the acute

stage versus the striking reductions or disappearance of such impairments in the chronic stages are consistent with the views of Jackson, von Monakow, Goldstein (1948) and Riese (1960). In the tradition of Jackson and von Monakow, and his teacher Goldstein, Riese (1960, p. 295) observed, "One of the main reasons why the interpretation of brain lesions has been a mechanical rather than a dynamic one, has been the total neglect of one of the basic consistuents of disease and the effects of injury, namely time." These findings are consistent with earlier reports of Broca (1865), Vulpian (1866), Kussmaul (1877) and Bastian (1898) which emphasized the functional plasticity of the brain and its dynamic capacities for early or later spontaneous reorganization and compensation of cerebral functions following insults in adults as well as children (Smith, 1984).

Commissurotomy Studies

Consistent with our findings and previous reports of poor Raven Matrices scores following either right or left hemisphere lesions, studies of commissurotomy have reported that either the left or right hemisphere alone may be capable of adequate performance on Raven's tests. Based on RPM and RCM performances of two patients with complete commissurotomy (N.G. and L.B.) and one patient with left and one with right hemispherectomy, Zaidel et al., (1981) reported no differences in Raven performance as a function of hemispheric laterality. They described their findings as evidence of "bihemispheric competence" for the Raven tasks. However, interpretation and generalizability of their findings to normal and clinical populations are qualified by the small sample size, the unique nature of their clinical material and the association of numerous confounding factors.

The two hemispherectomy cases consisted of children operated at ages 10, and at 7 years 9 months for lateralized lesions incurred in early life. Long-term followup studies of hemispherectomy in children and young adults for lesions incurred early in life have demonstrated capacities for normal and even superior development of both verbal and nonverbal cognitive function, regardless of the hemisphere removed (Smith, 1972a, 1983). While such studies revealed a wide range of outcomes, the degree of development was dependent on the status of the residual hemisphere (Smith, 1983, 1984). Thus, rather than supporting "*bi*hemispheric competence" for Raven performance in the normal brain, Zaidel et al.'s findings for the two hemispherectomy patients are compatible with numerous reports of the remarkable capacity for reorganization of function inherent in the young brain.

Zaidel et al. also cited findings in two commissurotomy patients in support of their conclusion of bihemispheric competence for the Raven Matrices. These two patients, N.G. and L.B., were selected from a series of 12 patients with commissurotomy.

Neuropsychological followup studies of the total sample of 12 commissurotomy patients were reported by Campbell, Bogen and Smith (1981). They pointed out that in contrast to negligible changes in VIQ, N.G. and three other patients showed marked postcommissurotomy drops in WAIS PIQs ranging from 10 to 28 points. Analysis of neurological and neurosurgical data revealed evidence of right structural lesions in only these four patients.

Although the RCM test was not administered to N.G. preoperatively, comparisons of pre-operative and 4-year postcommissurotomy Wechsler scores revealed a 10-point PIQ decline (from 74 to 64). Her 4-year postcommissurotomy RCM score (16) was also markedly subnormal.

Campbell et al. cited the striking findings in these four cases with right structural lesions as evidence that complete commissurotomy, which severed the interhemispheric connections, had disrupted interhemispheric compensatory mechanisms for recovery of nonverbal functions reorganized by recruiting of intact structures in the left hemisphere via the corpus callosum following earlier right structural damage.

The second commissurotomy patient cited by Zaidel et al., L.B., did not show evidence of a right structural lesion, and did not show marked declines in PIQ following commissurotomy. Moreover, in contrast to N.G.'s subnormal score on the Raven Coloured Matrices 4 years after commissurotomy, L.B.'s score 2–5 years postoperatively was in the normal range (32).

Raven performances by these four cases reflect effects of the various interacting factors and processes underlying disorganization and varying degrees of subsequent cerebral reorganization in a small, highly selected unique clinical population. Interpretation of the findings as evidence of bihemispheric competence for the Raven Matrices in normal cerebral development is clearly qualified.

Unilateral Neglect

Association of unilateral neglect with poor Raven performances, especially in patients with right, and right posterior hemisphere lesions, has been abundantly reported (Basso et al., 1973; Colonna et al., 1966; Colombo et al., 1976; Costa et al., 1969; Piercy et al., 1962). Although qualified by the confounding effects of uncontrolled sources of ambiguity, including many of the factors described above, Doehring, Reitan & Kløve, (1961) reported that patients with right homonymous hemianopia showed most frequent and severe impairment in verbal functions, in contrast to those with left homonymous hemianopia who showed most frequent and severe deficits in nonverbal tasks.

Using the previously described criterion of selection of answers located on the side of the page ipsilateral to the lesion as an index of unilateral neglect, our findings showed highest incidence of neglect in patients with right posterior lesions. Of 32 patients for whom protocols were available, 4 of 10 patients with acute right posterior lesions demonstrated neglect in RCM performances compared to only 1 of 9 with acute left posterior lesions. None of the 14 patients with frontal lesions showed neglect. While the 4 with right posterior lesions showing position preferences had poor RCM scores, only 1 of the remaining 6 who did not show position preferences had a normal score. One patient with a right posterior lesion showed consistent selection of items *contralateral* to the side of the lesion. A similar case was reported by Costa et al. (1969). Interestingly, of the 5 patients in our study with documented visual field defects this was the only patient who showed a position preference on the RCM.

In a more recent study, Gainotti, D'Erme, Villa and Caltagirone (1986) devised version of the Raven Matrices designed "to minimize the influence of unilateral spatial neglect without changing the essential features of the test." They concluded that when the influence of unilateral neglect was minimized, there were no differences as a function of hemispheric site of lesion (left versus right). However, this study was based on analysis of a sample which included patients with resolving and evolving lesions tested in acute as well as chronic stages. The patients were not differentiated according to these critical factors, nor were they differentiated according to anterior posterior locus of lesion. This recent study illustrates the persistence in the literature of an unwarranted tacit assumption in studies

comparing patients with left- versus right-sided lesions, namely, that the hemisphere contralateral to the lesion is intact. Despite the methodological difficulties described above it is interesting that Gianotti et al. reported that aphasic patients with comprehension difficulties did more poorly than the other groups of left brain damaged patients on the Raven Matrices. This finding is consistent with Broca's 1865 report (Berker, Berker & Smith 1986) as well as findings in our studies of aphasics and hemispherectomy patients indicating the role of the right hemisphere in comprehension of speech. Our studies have revealed that aphasic patients with marked comprehension deficits typically show bilateral manual motor deficits and poor Raven scores indicating pathological involvement of right hemisphere mechanisms in association with the left-sided cerebrovascular lesion.

From studies of adults with hemispherectomy cited above, it is obvious that the presence of right homonymous hemianopia following left hemispherectomy is not associated with impaired RCM performance, whereas persisting left homonymous hemianopia from 1 to 30 years following right hemispherectomy has been consistently associated with persisting poor RCM scores.

Thus, it is obvious that poor performance on RCM cannot be attributed solely to right- or left-sided visual field defects or visual neglect alone. Instead, poor RCM scores are not surprising in patients with left homonymous hemianopia which reflects a right posterior lesion. Our findings therefore fail to provide evidence supporting any necessary relationship between neglect, visual field defects and severity of impairment of RCM performance.

Factor analytic studies of the Raven tests have reported the existence of several discrete underlying factors (Corman & Budoff, 1974; Dolke, 1976). These findings suggest that "nonverbal" reasoning is not a unitary mental process. Instead they indicate that solution of the various Raven items depends on a complex of specific and discrete nonverbal mental functions, one or more of which may or may not be variously involved in other visual perceptual, spatial constructional, visuoideational or in Jackson's term "visuopsychic" processes.

Language And Left Hemisphere Involvement In Raven Performance

As noted above, previous studies (Basso et al., 1973; Colonna et al., 1966; DeRenzi et al., 1965) have cited findings of poor RCM scores in patients tested at different stages after onset of left hemisphere lesions as evidence of language mediation in processing of RCM problems. This contention however, is apparently incompatible with several reports of normal to superior RCM performances by severely aphasic patients (Archibald et al., 1967; Costa et al., 1969; Kertesz et al., 1975; Zangwill, 1964; Smith et al., 1972b).

Age norms for the RPM provide further evidence against language mediation in Raven performances, and reflect a common characteristic shared with most other tests of nonverbal function. The rate of steady and increasing declines in RPM scores from the age of 25 with each successive decade (Raven, 1975) closely resembles, but is far steeper than, similar declines demonstrated for all the WAIS-R performance subtests with increasing age. In contrast to the progressive declines with age demonstrated in WAIS-R performance subtests and Raven scores, the WAIS-R Vocabulary subtest shows a continuing gain with advancing age. The remaining Wechsler verbal subtests show relatively slight declines until the latest decades of life (Wechsler, 1981).

Qualitative analysis of Matrices problems also suggests that verbal strategies do not play an important role in their solutions. The difficulty of the items ranges

widely, from simple pattern matching that 3 year olds and even patients with severe verbal and nonverbal cognitive deficits can solve, to items that are correctly answered by a small percentage of the general population. Correct solutions can often be achieved by more than one strategy, and once solved, the logic underlying Raven items can be restated verbally. However, the solution of these problems lies not so much in verbal semantic logical processes, but in discerning the visual analogous reasoning processes underlying each matrix.

For example, the last, and presumably most difficult, item of the Standard Matrices is problem E12. It consists of a 3×3 matrix of circles, each with a number of loops either inside or outside the circumference of the circle. As with all Raven problems the lower right cell is missing and the subject must select the missing "squiggle" from alternates presented below the matrix. The underlying logic of the item is a simple math problem (e.g., $5 - 3 = 2$ or $2 + 3 = 5$). However, the central difficulty of this and other Raven items appears to be in determining what proposition the various arrangements of nonverbal squiggles are designed to convey. Otherwise, anyone with the most basic simple arithmetic skills could promptly give the correct answer.

The most compelling evidence contradicting claims of language mediation in Raven performance has been recorded in comparisons of adults with right- versus left-hemispherectomy for tumor. Despite persisting severe aphasia following left hemispherectomy, RCM performances showed no enduring deficits and were relatively intact. By contrast, all adults with right hemispherectomy showed intact language and verbal reasoning abilities, but persisting profound impairment in RCM and other nonverbal test performances (Burklund & Smith, 1972; Smith, 1972a, 1981).

Our population included 3 aphasics (all with gliomas) in the sample of 35 with acute, and 3 aphasics (2 with glioma and 1 with angioma) in the 22 tested in the chronic stage. All had left posterior lesions. Despite marked persisting aphasia, all three patients tested in the chronic stage showed normal Raven scores (range 28–35) and normal left hand Purdue Pegboard performances (21–29 pegs in 60"). Of the 3 aphasics tested in the acute stage, 2 with normal left hand Purdue Pegboard performances (24 and 23 pegs in 60") showed normal RCM scores (25 and 33). The third aphasic with the lowest and markedly subnormal RCM score (21) also showed a subnormal left hand Purdue Pegboard score (16 pegs in 60").

As noted above, our findings indicate that postrolandic structures of the right hemisphere play a critical role in RCM performance. Previous studies have demonstrated that aphasics as well as nonaphasics with left-sided lesions and poor RCM scores consistently show associated involvement of right hemisphere mechanisms (Smith, 1972b). Presence of associated right- as well as left-hemisphere involvement in many of such cases can be readily demonstrated by the Purdue Pegboard test. The accumulating findings strongly suggest that previous conflicting reports of association or dissociation of aphasia with poor Raven scores may be reconciled when specific factors determining condition of the brain, including age, time of testing, specific nature and locus of lesion, and especially presence of diaschisis and the status of the right hemisphere are taken into account.

Differing Patterns of Recovery In RCM Performances

Denes et al., (1978) reported that 24 patients with right hemisphere cerebrovascular lesions showed greatest gains in Set B when retested 2 months after admission. By contrast, 24 patients with left hemisphere cerebrovascular

lesions showed greatest gains in Set A. They cited these findings as evidence of greater left hemisphere competence for Raven Set B and greater right hemisphere competence for Set A.

Their interpretation however, is qualified by several factors, including the small reported group differences (for example, the right lesioned patients showed a mean gain of 0.6 points on Set A, versus a 1.5 point gain for the left lesioned patients); the heterogeneity of items within each subtest as documented in factor analytic studies cited above; and undocumented heterogeneity of the population samples (in which the effects of diaschisis, specific nature and intrahemispheric locus of lesion were not controlled).

Cerebral "Localization" And Nonverbal Reasoning

Consistent with the conclusions reported by Jackson over 100 years ago, our findings indicate that the right posterior region of the human brain plays a "leading" role in "visuopsychic" or visual ideational functions. Jackson's selection of the word "leading" was perhaps prompted by his observation that localizing a lesion that destroys a function and localizing a function are two different things. Jackson's careful observations led him to conclude that mental states arose *during* but not *from* activities of the brain, and that he could not conceive of any arrangements of matter that would produce mental states (Walshe, 1961).

In contrast to Jackson's view, Fried, Mateer, Ojemann, Wohns and Fedio (1982) reported in a study based on electrical stimulation of cortical sites during surgery in 10 epileptic patients prior to resection of the epileptic focus, that specific "visuospatial functions in the non-dominant hemisphere are as discretely localized as verbal functions in the dominant hemisphere." This and other recent as well as earlier studies correlating damage to, or disruption of specific cortical sites with selective cognitive impairment have been cited as evidence supporting the conclusion that cognitive "functions" can be "localized" to well defined and circumscribed cortical areas. However, Jackson maintained that no hypothesis of the integrative functions of the cortex could be built on "abrupt geographical localizations" (Walshe, 1961, p. 120).

Consistent with Jackson, Sherrington (1941, p. 228), observed that "To suppose that the roof-brain consists of point-to-point 'centres' identified each with a particular item of intelligent concrete behavior is a scheme 'oversimplified and to be abandoned.' Rather ... the contribution which the roof-brain in collaboration with the rest of the brain and spinal cord, makes toward integrated behavior will, when they are ultimately analyzed, resolve into components for which we at present have no names, having no conception of such processes."

More recently, Walshe (1961) noted that "Jackson's concepts were very early excluded from the mainstream of physiological interest. They have remained the heritage of the clinical neurologists, by a succession of whom they have been kept alive, primarily because of their correspondence with so many of the facts of clinical experience, and also in the hope that sooner or later they would attract and command the serious attention of professed neurophysiologists. It would be difficult to exaggerate the unfortunate influence of this dichotomy (i.e., the historical predominance of cerebral localization over Jackson's dynamic approach) on our knowledge of operational principles of the nervous system." However, continuing advances in more precise definitions of structure-function relationships will afford new contexts and opportunities for elucidation of the principles

underlying human brain function first suggested by Jackson over a century ago, and for definitions of specific dimensions of cerebral functions for which we currently have no names.

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