Intellectual functions in patients with lateralized frontal tumours

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Intracranial neoplasms have furnished the bulk of material for clinico-anatomical correlations of brain lesions and psychological abnormalities. While there is an enormous literature on clinical studies of patients with lateralized frontal tumours, the diversity of conclusions with respect to intellectual function reflects the numerous sources of ambiguity inherent in this clinical material (Smith, 1962b) and the subjective nature of clinical assessments. Despite the increasing introduction of systematic, objective, and controlled psychological studies of the effects of various types of brain lesions, there have been few such studies restricted to populations in which the site and nature of tumours had been based on neurosurgical and neuropathological findings.

The importance and paucity of such studies were reflected in a recent symposium on frontal lobe functions (Warren and Akert, 1964). Various reports on the effects of carefully designed frontal lesions in animal experiments and of random frontal lesions in human clinical populations reflected the continuing diversity of findings.

While the enormous pertinent literature cannot be reviewed here, Teuber's (1964) comprehensive survey reflects two growing concepts: (1) In contrast to earlier historical views based on many clinical and three psychological studies of brain tumour populations, later psychological studies consistent with Feuchtwanger's (1923) clinical study of 200 cases of penetrating brain wounds were cited as '... increasing evidence that frontal lesions, on the whole, have less effect on test intelligence ... than lesions in other areas of the human brain', and (2), except for specific language defects apparently unrelated to general intelligence, as in lower species, there are no marked or significant differences in effects of left or right frontal lesions on the so-called 'higher' mental functions unique to man.

Support for one or both these views was either implicit or expressly stated in four preceding reports on psychological impairment in patients with brain tumours and other lesions. While Teuber cited early

reports of maximal intellectual impairment in populations with frontal tumour by Rylander (1939, 1943) and Halstead (1947), he called attention to later studies by Pollack (1955) and Battersby, Krieger, and Bender (1955) reporting contradictory findings. The latter two and a third study by Battersby, Krieger, Pollack, and Bender (1953) apparently supported the view that there are no significant differences between effects of left and right frontal tumours, since all three studies generally concluded that the severity of the effects of cerebral tumours was the same, regardless of their locus.

Although the presence of aphasia in certain patients with left-sided tumours was duly noted, the methods of analyses of data in these three studies obscure possible differences in the effects of lateralized frontal tumours on higher mental functions for comparisons of all frontal vs. all non-frontal groups combined left and right frontal tumours in patients, tacitly assuming that there are no marked differences between the effects of lateralized frontal lesions on the various tests of higher mental functions. This assumption is supported by many clinical and psychological studies reporting no greater losses following frontal than non-frontal lesions, *e.g.*, by Feuchtwanger (1923), Jefferson (1937), Hebb (1939, 1941), and more recently by Chapman and Wolff (1959), Reitan (1964), Milner (1964). Although Milner demonstrated greater losses in verbal fluency following left than right frontal lobectomy for relief of seizures, comparable slight impairment in I.Q.s, regardless of the site of excisions, indicated that reduced verbal fluency was unrelated to general intelligence.

The assumption is also supported by psychological studies of brain tumour patients (Rylander, 1939, 1943; Halstead, 1940, 1947) and of patients with diverse brain lesions (Shure and Halstead, 1958) describing greater impairment following frontal lesions but no significant differences between left, right, or bilateral prerolandic lesions on higher mental functions.

These findings, however, clearly contradict those

of many earlier investigators, including outstanding students of human brain functions, *e.g.*, Jackson (1874), Phelps (1897), Dana (1915), Goldstein and Gelb (1918), Dew (1922), Papez (1929), Worster-Drought (1931), German and Fox (1934), Busch (1940), Goldstein (1948), whose observations on the effects of tumours and other brain lesions led to the common conclusion that left frontal lesions resulted in more marked and frequent impairment than right frontal (Jackson, 1874) or lesions elsewhere in the brain (others cited above.)

Since previous comparisons of objective intelligence tests in patients with lateralized frontal tumours have been based on small populations, this report of findings in a study of 128 brain tumour patients has been restricted to comparisons of the effects of left and right frontal tumours on the results of the same intelligence test used by Pollack (1955) and Battersby *et al.* (1953), the Wechsler-Bellevue I test (Wechsler, 1944). While Wechsler-Bellevue I.Q.s have been found to be frequently unreliable and insensitive indices of the presence, nature, or degree of organic intellectual impairment in patients with diverse types of brain lesions, the Wechsler-Bellevue test consists of five separate verbal and five non-verbal or performance subtests which provide 10 independent measures of different aspects of intelligence. Standardization data for each subtest are available for relatively large samples of normal subjects. In the absence of premorbid measures, the presence or absence of impairment may be assessed by comparisons of individual subtest and total scores of brain-damaged patients with those of normal subjects of the same age. Since the 10 subtests also involve different modalities, specific effects of lateralized lesions on test modalities may be differentiated from impairment of the general intelligence this instrument was designed and is assumed to measure.

The findings presented here will be restricted to detailed comparisons of left and right frontal tumour groups only. Data and analyses for this report have thus been organized for evidence bearing on two questions:

1 Do patients with left frontal tumours show lower total intelligence test scores than those with right frontal tumours?

2 If so, are the lower total scores indicating greater intellectual impairment due to selective defects restricted to performances in tests involving only a single modality?

SUBJECTS

NEUROLOGICAL INSTITUTE Thirty-one right-handed patients with unilateral prerolandic tumours were

selected from 120 right-handed and eight left-handed patients with tumours verified by surgery and/or necropsy. This population consisted of all such cases referred for psychological testing at the Neurological Institute, N.Y.C., between 1946 and 1960 to whom the Wechsler-Bellevue I test had been administered. Patients with bilateral frontal tumours or tumours overlapping the Rolandic fissure were excluded from the present study.

The 14 left frontal cases consisted of six astrocytomas, four glioblastomas, three meningiomas, and one metastatic tumour. Eleven patients were tested only preoperatively and three shortly after surgery. While there were no formal tests for aphasia, mild language disturbances were noted in four patients at the time of testing.

The 17 right frontal cases consisted of four astrocytomas, two glioblastomas, 10 meningiomas, and one undifferentiated tumour. Thirteen patients were tested only preoperatively and four post-operatively. Since there were more intrinsic and malignant tumours in the left frontal group, possible differences as a function of type of tumour were studied by comparing patients equated for type of tumour and for age. Although more marked effects in cases with glioblastomas (the most highly malignant and invasive tumour, often surrounded by extensive oedema) were expected, test scores failed to reveal systemic differences as a function of the type of tumour in the 31 patients with lateralized frontal lesions. Similarly, as reported by Pollack (1955) and consistent with findings based on pre-operative-postoperative tests of the same patients in our laboratory, the 10 subtests showed no significant differences between patients tested only before or after surgery.

RESULTS Taken as a whole, the mean I.Q. of 95.55 for the 31 patients with lateralized frontal tumours suggests that neoplasms in either the right or left frontal lobe result in only slight impairment of intellectual functions as measured by the Wechsler-Bellevue test. Since 68 patients with lateralized non-frontal tumours, consisting of 34 right- and 34 left-sided tumours had a total mean I.Q. of 91.46, these results are apparently consistent with Teuber's observation that '... frontal lesions, on the whole, have less effect on test intelligence ... than lesions in other areas of the human brain'.

In terms of the two questions reflecting the focus of the present study, however, separation of the two frontal groups suggests that comparisons of all frontal and all non-frontal groups are misleading. For although comparable in mean age, education, and sex distribution, the mean I.Q. of the total frontal population obscures a marked difference in mean

I.Q.s of the left (90-71) and the right frontal (99-53) groups. Despite the small numbers, this difference approached statistical significance at the 0.05 level when using the more stringent two-tailed *t* test ($t = 2.132$, two-tailed required value = 2.14). In terms of the first question, therefore, an 8.82 point difference in mean I.Q. indicates markedly lower intelligence test scores by the patients with left lesions than those with right frontal lesions.

Considering the data in terms of the second question, namely, is the lower I.Q. due to defects restricted to verbal subtests, comparisons of subtest scores in Table I show lower scores by the left frontal group in all 10 subtests. While numerous studies have reported systematically lower verbal subtest scores by groups with left-sided lesions, and systematically lower performance subtest scores by groups with right-sided lesions, in addition to different findings reported by Smith (1966), the results of comparisons of the two frontal tumour groups show lower verbal and lower performance weighted score sums by the left frontal group.

Since the left frontal group included four mildly aphasic patients, and aphasia has been described as a specific manifestation of impairment in general intelligence, comparisons were also made of the scores of the two lateralized frontal groups when the four aphasics were excluded.

As Table I shows, exclusion of the four mildly aphasic patients resulted in the expected diminution of differences in verbal subtest scores of the 10 non-aphasic left frontal and the 17 right frontal groups. The non-aphasic left frontal group, however, shows

lower aggregate performance as well as verbal weighted score sums than the right frontal group, and in addition to lower scores in the five verbal subtests, lower scores in three of the five performance subtests.

The increment in each of the five performance subtests by the left frontal group when the four aphasics are excluded reveals that in addition to the expected greater impairment in tests of mental functions involving language, the four aphasics were also more markedly impaired than the 10 patients with left frontal lesions in non-language tests of mental functions. Although this might be interpreted by some as evidence of greater impairment in general intelligence associated with aphasia, this interpretation is qualified by a marked difference in the mean ages of the 10 non-aphasic left frontal patients (41.50 years) and the four aphasics (54.75 years). For while it is all too frequently overlooked in analyses of effects of tumours (*e.g.*, Rylander, 1939, 1943; Halstead, 1947) and other types of lesions (Smith, 1962a), in addition to the increased incidence of aphasia with advancing age, markedly greater impairment in older patients was also observed in comparisons of psychological test scores of the total population of the present study as well as in another independent sample of brain tumour patients for whom psychological test data were available (Pollack, 1955).

COMMENT While the above findings suggest that left frontal tumours are more likely to result in marked impairment in general intelligence than

MEAN WECHSLER-BELLEVUE I INTELLIGENCE TEST SCORES FOR FRONTAL TUMOUR GROUPS AND CONTROLS

	Neurological Institute			Mt. Sinai		Group Totals				Spinal Cord (Mt. Sinai)		Normals (Wechsler's)
	Left	Non-aphasic Left	Right	Left	Right	Left	SD	Right	SD			
No. of cases	14	10	17	4	6	18	—	23	—	14	135	
Test												
Information	8.29	(9.10)	10.06	7.75	12.17	8.17 ¹	2.66	10.61	3.66	11.29	9.38	
Comprehension	6.93 ^a	(7.40)	10.00	7.50	11.17	7.06 ^a	2.82	10.30	3.03	10.21	9.78	
Digit span	7.07	(7.60)	7.88	6.25	9.17	6.89	3.42	8.22	2.74	6.92	8.47	
Arithmetic	6.14	(7.10)	7.71	7.75	9.17	6.50	4.32	8.09	3.02	9.00	9.03	
Similarities	6.29	(6.30)	8.35	6.75	10.83	6.39 ^a	2.21	9.00	3.78	9.71	9.52	
Picture arrangement	6.57	(7.50)	7.06	5.00	6.67	6.22	2.98	6.96	2.75	7.14	7.81	
Picture completion	7.53 ¹	(7.70)	9.76	3.75	10.00	6.67 ^a	2.03	9.83	2.68	8.36	8.64	
Block design	6.00	(6.10)	6.24	4.50	6.50	5.67	3.05	6.30	3.03	7.21	8.23	
Object assembly	7.86	(8.30)	8.00	7.00	6.50	7.67	2.86	7.61	3.43	7.79	8.86	
Digit symbol	4.57	(4.70)	5.71	5.00	5.83	4.67	1.57	5.74	1.94	6.14	7.70	
Verbal weighted score sum	34.71 ¹	(37.50)	44.00	36.00	52.50	35.00 ¹	12.08	46.22	14.26	47.64	46.63	
Performance weighted score sum	32.50	(34.30)	36.76	25.25	35.50	30.89	9.69	36.43	10.32	36.50	41.24	
Full-scale I.Q.	90.71 ^a	(91.90)	99.53	86.25	103.50	89.7 ^a	11.04	100.6	12.17	101.50	—	
Age	45.29	(41.50)	46.76	44.00	48.17	45.00		47.13		46.35	40.49	
Sex (N males)	9	(7)	11	0	4	9		15		7	—	
Education	10.07	(11.00)	10.29	10.75	13.17	10.22		11.04		8.71	—	

¹Difference compared to right frontals statistically significant at 0.05 level

^aDifference compared to right frontals statistically significant at 0.01 level

^aDifference compared to NI right frontals approached statistical significance at 0.05 level ($t = 2.132$, required value 2 tailed test $t = 2.14$). When combined with Mt. Sinai groups, the difference in mean I.Q. of 18 lefts (89.7 — SD 11.04) with mean age 45.00, education 10.22 years and 23 right frontals (100.6 SD 12.17) with mean age 47.13, education 11.04 years, was significant at the 0.01 level ($t = 2.99$)

right frontal tumours, they are limited by the absence of premorbid scores and the small size of the two samples. Even assuming that there were no significant differences in premorbid capacities, and that the results of the present study reflect valid differences as a function of the tumours in these two populations, how can we be sure that such differences were not a random reflection of numerous undefined pathophysiological reactions such as oedema, compression, effect on the vascular supply, increased intracranial pressure, and the like? We cannot.

The findings are also qualified by the nature and selection of the sample as well as by its size. The population was restricted to patients in whom the presence and locus of brain tumours had been verified by surgery and/or necropsy only. This sample included, moreover, only those cases in a special voluntary hospital, who were referred for psychological testing, and who were capable of undergoing tests. This population is therefore not only a highly selected sample of patients with acute lateralized frontal lesions, but a highly selected sample of brain tumour patients that comprised only a fraction of such cases admitted to the Neurological Institute during the 14-year interval. To test the validity of the findings in comparisons of lateralized frontal tumours in the above sample, similar comparisons were necessary in an independent sample of this clinical material for which psychological test data were available. Fortunately, the study cited by Teuber (Pollack, 1955) contained data including scores for the same Wechsler-Bellevue subtests. Similar data and analyses in terms of the two questions cited above were organized for all patients with lateralized frontal tumours in that study.

MT. SINAI HOSPITAL SERIES

SUBJECTS This sample consisted of 81 patients in a 'nearly all consecutive' series of brain tumour cases undergoing surgery at the Mt. Sinai Hospital, N.Y.C. As noted above, the findings had been cited by Teuber as evidence against the traditional view of greater impairment in test intelligence by frontal than non-frontal lesions. Among other conclusions, Pollack (1955) reported 'no significant differences between pre- and postrolandic lesions could be found on any test'.

Since this study tested the claims of greater intellectual defects following left, right, or bilateral frontal tumours, Pollack compared all frontal and non-frontal cases. As noted above, however, possible differences between left and right frontal tumours are obscured by this method of analysis. Further comparisons of Wechsler-Bellevue scores of patients

with lateralized frontal tumours thus provided a test of the reliability of the findings in the Neurological Institute frontal group comparisons. Since scores on the same tests were also available for 12 Mr. Sinai patients undergoing surgery for spinal cord lesions, Wechsler-Bellevue subtest scores for these patients and for 135 normal subjects between the ages of 40 and 49 years in Wechsler's standardization samples (Wechsler, 1944) are included in Table I for comparison with those of the tumour groups.

RESULTS The 81 patients included 10 with lateralized prerolandic lesions. Taken as a whole, the mean I.Q. of these 10 patients (96.60) differs only slightly from that of the combined Neurological Institute groups (95.55) and also suggests that the presence of a frontal tumour has little effect on Wechsler-Bellevue full-scale I.Q.s. The mean I.Q. of 56 patients with lateralized (24 left and 32 right) non-frontal tumours (96.23) is almost identical with that of the frontal group. Thus, these comparisons of combined frontal and combined non-frontal tumour groups suggest no appreciable differences between the effects of lateralized tumours on intellectual functions and are consistent with Pollack's findings and Teuber's observations.

The mean I.Q. of the combined left and right frontal tumour groups in the Mt. Sinai sample, however, conceals an even greater difference in mean I.Q. of the four left frontal cases (86.25) and the six right frontal cases (103.50) than that shown in the Neurological Institute frontal group comparisons. Indeed, despite the very small size of the Mr. Sinai samples, a one-tailed test of the hypothesis predicting lower scores by the left frontal group is statistically significant at the 0.05 level ($t = 2.33$).

The higher mean education of the right frontal group (13.17 years vs. 10.75 years for the left frontal group) qualifies interpretation of this difference as a confirmation of the hypothesis. However, the slight difference between mean I.Q.s of the Neurological Institute right frontal group (99.53, mean education 10.29 years) and that of the Mt. Sinai group (103.50, mean education 13.17 years) suggests that the 2.88 year difference in mean education had little effect on full-scale I.Q.s. Thus, even assuming a slightly higher premorbid capacity for the Mt. Sinai right frontal tumour group, normal mean I.Q.s of the two right frontal tumour groups reveal little evidence of impairment of general intelligence.

In addition to a markedly lower mean I.Q., the left frontal tumour group shows a pattern of consistently lower subtest scores that is practically identical with that in the Neurological Institute group comparisons. Except for a slightly higher

score in the object assembly test, due to complete inability of a 60-year-old patient with a right frontal tumour to assemble any of the figures in this subtest, scores in all subtests, as well as aggregate verbal and performance scores of the left frontal cases, were lower than those of the right frontal group.

COMMENT In terms of the first question, do patients with left frontal tumours show lower intelligence test scores, the results of comparisons of lateralized frontal groups in the two samples were consistent. Combining the Neurological Institute and Mt. Sinai populations, the difference between mean I.Q.s (18 left-sided, 89.7 vs. 23 right-sided tumours, 100.6) is statistically significant at the 0.01 level. And in terms of the second question, are the lower total scores indicating greater intellectual impairment by the left frontal tumours due to selective defects in subtests involving only a single modality, the results of comparisons of the two populations are also consistent.

As indicated above, the proportions of cases with intrinsic, malignant, and invasive tumours in the two groups differed markedly. Since astrocytomas and glioblastomas are often associated with extensive surrounding oedema, and the 18 patients with left frontal tumours included 10 such cases compared with only eight in the 23 patients with right frontal tumours, differences were compared as a function of the type of tumour. Consistently lower mean I.Q.s of the cases with left frontal tumours were also shown in comparisons of six cases with astrocytomas (I.Q. 92.50), four glioblastomas (95.25), and five meningiomas (87.20) with similar right frontal cases consisting of five astrocytomas (102.80), three glioblastomas (101.00), and 12 meningiomas (98.75).

Scores of the left frontal cases are lower than the right frontal cases in all subtests in the Neurological Institute group comparisons, and show only a single exception to this pattern in Mt. Sinai group comparisons. When both groups are combined, scores of the 18 left frontal cases are lower than those of the 23 right frontal cases in nine of the 10 subtests, with a negligible difference (0.06) in the single exception, object assembly subtest. Differences were statistically significant at the 0.05 level in the information subtest, and at the 0.01 level in comprehension, similarities, picture completion, and verbal weighted aggregate scores.

As noted above, omnibus I.Q.s are aggregate and often unreliable indices of organic intellectual deterioration. Specific defects restricted to certain test modalities, for example, may give a totally erroneous indication of severe intellectual impairment when actually intellectual functions may be relatively intact and lower total scores a reflection

of impairment of test modalities. Conversely, I.Q.s may obscure selective defects in specific subtests.

Comparisons of the two right frontal groups with patients undergoing surgery for spinal cord lesions and with 135 normal subjects between 40 and 49 years old show markedly subnormal scores by the patients with right frontal tumours in block design, object assembly, and digit symbol subtests. Scores in other subtests, however, exceeding or approaching those of the two non-tumour groups indicate normal mental capacities. Thus mean I.Q.s of the two right frontal groups in the normal range apparently obscure subnormal scores in these performance subtests. Since verbal tests indicate apparently intact higher mental functions, the impairment in certain performance subtests by the patients with right frontal tumour suggests the presence of a selective modality defect in various aspects of visual functions.

Thus, while both left and right frontal groups show impairment in the same tests of mental capacities involving visuo-spatial functions, if assessments of effects of left and right frontal tumours on higher mental functions were based solely on such visuo-spatial tests, the results would lead to the erroneous conclusion of impairment in both groups, although to a slightly greater degree following left frontal tumours. And if assessment were based solely on verbal measures of higher intellectual functions, the findings would indicate negligible effects of right frontal tumours in contrast to marked impairment following left frontal lesions.

Comparisons of scores in verbal and non-verbal measures of the combined Neurological Institute and Mt. Sinai groups with left vs. those with right frontal tumours and the two control groups, however, reveal a marked difference in effects of lateralized frontal tumours on higher mental functions. While both groups show subnormal scores in all performance subtests except for picture completion, the markedly subnormal score in picture completion by the left frontal tumour group is consistent with similarly subnormal scores in the remaining four performance subtests and in the five verbal subtests. The score in the picture completion subtest of the patients with right frontal tumours, however, is slightly above that of the normals as well as showing a statistically significant difference at the 0.01 level when compared to the subnormal score of the patients with left frontal tumours. Since scores of the patients with right frontal tumours in verbal subtests either exceed or approach those of the two control groups, these non-visual measures of intellectual functions and the score in the picture completion subtest, indicating normal or intact

capacities, strongly suggest that the reduced scores in the four performance subtests by the patients with right frontal tumours are due to impairment of specific visual functions involved in these tasks. Thus, while right frontal tumours resulted in a modality specific defect, general intellectual functions remain relatively intact.

Comparisons of scores of the patients with left frontal tumours with those with the right-sided tumours and the two control groups, however, reveal impairment in all 10 subtests. In addition to slightly greater impairment in three of the four performance subtests showing subnormal scores by those with right frontal tumours, markedly lower scores by those with left-sided tumours in picture completion and the five verbal subtests clearly indicate the reduced scores in all 10 subtests following left frontal tumours are not due to a modality specific defect. Since, in addition to the expected impairment in both non-aphasic and aphasic patients with left frontal tumours, scores in non-verbal tests of higher mental functions also reveal marked impairment, the findings of the present study strongly suggest that left frontal tumours in the acute stage (immediately before or shortly after surgery) result in impairment of 'higher' gnostic or conceptual capacities involved in these measures of general intelligence.

DISCUSSION

Despite the increasing introduction of objective psychological tests and refinements in systematic and controlled studies, the continuing diverse conclusions may suggest there have been few if any advances in attempts to differentiate effects of variously situated lesions on man's higher mental functions. Moreover, reminiscent of the 1,000-year search for a sensorium commune, the current literature reflects historical partisan controversies with claims of maximal impairment following variously situated lesions cited as evidence of the greater roles of certain favoured brain structures in intellectual functions.

Recent evidence that not all frontal lesions result in marked defects described in earlier clinical studies has been followed by claims of the greater importance of certain posterior areas. Based on comparisons of frontal vs. posterior or left vs. right-sided lesions, some investigators have interpreted their findings (*e.g.*, Jefferson, 1937; Chapman and Wolff, 1959) as confirmation of Lashley's earlier (but later revised) views that regardless of the locus of lesions, the critical factor determining the presence and degree of intellectual impairment was the amount of cerebral tissue destroyed.

Jackson (1874), however, observed that the most important structures in the right hemisphere were in the posterior regions, while the most important ones in the left hemisphere were anterior. Although Russell (1948) emphasized the importance of the frontal lobes in the development of man's higher capacities, he reported that destruction of white matter in the left temporo-parietal region in adults 'has a disastrous effect on mental faculties of all kinds, including speech mechanisms'.

Although comprehensive psychological studies of long-term effect of penetrating gunshot wounds of the brain in 232 men showed systematic losses for only a small (10 cases) sample with left temporo-parietal wounds, Teuber's findings were consistent with those in a study of effects of penetrating dominant hemisphere wounds in 46 patients. Schiller (1947) reported that language and non-language tests of mental functions showed the more widespread the lesion and the farther back up and along the slant of the Sylvian fissure, the more pronounced was the loss.

While noting the consistent findings in studies of effects of penetrating brain wounds, Smith (1962a) also cited similarly consistent findings of marked losses in higher mental functions following specific bilateral frontal lesions (Smith, 1962a, 1964). Since these surgically designed lesions were bilateral, the results clearly suggest there are specific frontal areas in one or both lobes, damage to which results in more marked defects than similar or even larger lesions in other frontal areas. Obviously, in the light of the above, it is possible, indeed probable, that in view of the complex interrelationships of diverse mechanisms involved in total brain functions, there are several regions in the brain in which a lesion will result in greater impairment than similar lesions in other brain areas.

Arguing against earlier findings of greater impairment in frontal than non-frontal tumours, Teuber called attention to the large size of the frontal lobes and the greater amount of 'silent' areas wherein a frontal tumour might grow to a larger size than a non-frontal growth before manifesting sensory or motor symptoms. While the consistent findings of greater losses following frontal tumours described above may reflect undefined selection factors, they cannot readily be attributed to larger neoplasms. A moment's consideration will show that left frontal tumours generally betray their presence earlier than comparable right frontal growths because of the emergence of symptoms reflecting the unique role of left frontal areas in language functions.

This logical expectation is borne out by age comparisons of lateralized frontal tumour groups in studies by Rylander (1939), Halstead (1947), and

McFie and Piercy (1952a, b) showing consistently younger ages by the groups with left frontal neoplasms. Moreover, similar comparisons of left and right frontal tumour groups in the latter two studies also showed marked losses by patients with left frontal tumours and relatively slight impairment following right frontal tumours.

Poorer performances in nine of 12 measures (with only slight differences in the remaining three) were shown by eight patients with left frontal tumours compared with nine with right frontal tumours in one study (McFie and Piercy, 1952a). In a second study, McFie and Piercy (1952b) reported that failures in Weigl sorting tests in 74 patients were significantly greater in patients with dominant hemisphere lesions. More detailed analyses for differences as a function of locus and site, however, showed the greatest differences in comparisons of the two frontal groups. Of 18 patients with lesions encroaching upon or within the left frontal lobe, 13 (72.2%) failed this test, compared with only one of 18 with similar right-sided lesions. Thus, as McFie and Piercy noted, this finding suggested a difference in intellectual functions of the two frontal lobes apart from language functions, which may be impaired by left frontal lesions. And just as comparisons of all frontal and all non-frontal tumours may obscure significant differences as a function of laterality, comparisons of left frontal and non-frontal groups in this study showed that the difference between the two groups (13 of 18 failures in the left frontal cases vs. nine of 24 in the left non-frontal cases) was statistically significant at the 0.05 level ($\chi^2 = 4.97$).

Detailed findings for non-frontal and bilateral tumours in the populations of the present study will be presented elsewhere. However, while marked impairment in both verbal and non-verbal tests was occasionally noted for patients with non-frontal tumours, there were fewer such cases than in the left frontal group, and comparisons of mean I.Q.s of 58 patients with left (93.15%) and 66 with right (94.01%) non-frontal tumours failed to reveal postrolandic hemispheric differences corresponding to those in prerolandic comparisons.

In view of numerous studies of smaller populations with tumours and other types of lateralized prerolandic lesions reporting negligible differences, how can the findings of the present study be reconciled with apparently contradictory findings? Some of the apparent differences may be reconciled when the types of lesion, their age and dynamics, patients' ages, the nature of tests used, and other factors, are taken into account. The findings of the present study, for example, are based on tests of adult patients (mean age 46.2 years) with lateralized frontal tumours during the acute stage, *i.e.*, immediately

before or just after surgery. The importance of age in studies of this clinical material is indicated in Bailey's (Bailey, Buchanan, and Bucy, 1939) findings that mental disturbances characteristic of frontal and temporal tumours in adults were rarely if ever observed in children.

The patient's age and type of lesion also markedly differed in comparisons with the studies of Hebb (1939, 1941). Hebb reported that left frontal lobectomies in four patients and right frontal lobectomies in two for the relief of seizures had little apparent effect on language and other intelligence tests. However, in his later study, Hebb (1941) called attention to the early age at which lesions in the four patients with left frontal lobectomy had been incurred and withdrew his inference that the left frontal pole might be no more essential to language than to other intellectual functions.

The importance of age was also emphasized in a review of results of hemispherectomies in children (infantile hemiplegia with epilepsy) and adults (gliomas). Obrador (1964) noted that in contrast to adults transference of speech from one hemisphere to the other seemed to be the rule in children up to the age of about 15.

The greater impairment in non-verbal and verbal tests of mental functions in adults with left prerolandic tumours in the acute stage suggests that specific left frontal structures play a greater role in adult mental functions than corresponding right frontal structures. The relatively slight defects following right frontal tumours described above were also consistent with comparisons of unilateral leucotomies. Petrie (1952) observed marked changes resembling those following bilateral cuts in four patients with left frontal leucotomy and slight effects in four patients with right frontal leucotomy. It is also interesting to note that the most malignant type of tumour, glioblastoma multiforme, studied in 495 patients showed the longest survival by those with right frontal growths (Roth and Elvidge, 1960).

SUMMARY

Although qualified by the numerous sources of ambiguity inherent in this clinical material, comparisons of objective intelligence tests of the largest brain tumour populations examined to date showed consistent findings of greater losses by right-handed patients with left than right frontal tumours. Despite differing findings in previous studies including smaller numbers of patients with diverse frontal lesions, the results of the present study confirm earlier clinical observations of more marked and frequent impairment following diverse lesions in the left than the right frontal lobes.

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