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INTELLECTUAL CHANGES FOLLOWING TEMPORAL LOBECTOMY FOR PSYCHOMOTOR EPILEPSY

PRELIMINARY COMMUNICATION

BY

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The principal concomitants of psychomotor epilepsy have been well described by Gibbs, Gibbs, and Fuster (1948). According to them :

> " The chief clinical manifestations of psychomotor seizures may be described as follows : The patient becomes confused and as a rule amnesic but does not usually lose consciousness. His movements appear purposeful but are poorly coordinated and his manner is frequently negativistic. In general his behaviour is that of a person acting out a bad dream. Often during the seizure there are manifestations of fear or rage with screaming and shouting. In most seizures the movements are simple, repetitive and more or less automatic."

The patients with whom the present report is concerned were selected for operation (temporal lobectomy) " upon the evidence, first clinical, then electroencephalographic, that a single dominant focus existed in the anterior part of a temporal lobe ; secondly, that the seizures had not been controlled by adequate anticonvulsant therapy" (Hill, 1953).

During the course of routine psychological testing, it was observed that some of the patients who underwent the operation showed a gross learning deficit on certain psychological tests, although their intelligence level as measured by other tests showed no decline. For this reason, a testing programme gradually developed which was aimed at clarifying the nature of this deficit and establishing its reliability. The present paper presents preliminary findings on a number of patients with respect to intellectual changes before and after the operation. Since the investigation developed gradually out of clinical requirements, not all of the patients have been given all of the tests.

Review of the Literature

The literature concerned with the effects of temporal lobectomy is relatively sparse, particularly where the operation is performed for the relief of focal epilepsy without complicating factors such as tumours. Reports on psychological changes following the operation are both infrequent and usually quite inadequate, in so far as the need for statistical tests of significance is ignored and the possible influence of various relevant factors left uncontrolled.

In the most recent work attention has been mainly confined to consideration of the effects of the operation on the number of fits the patient suffers, and the possible intellectual changes resulting from this operation have been largely ignored or discussed in very general terms. Thus, Bailey and Gibbs (1951) reported on the post-operative status of 25 cases where the disturbance was confined to one lobe. They reported that no aphasic disturbances took place, but although intelligence and other psychological tests were given, no results were reported. Green, Duisberg, and McGrath (1951) investigated pre- and post-operatively 23 patients failing to respond to systematic medical therapy and demonstrating spontaneous electroencephalographic spiking in the anterior temporal areas. Although the Wechsler Intelligence Scale was given to these patients, no results were reported.

Similar studies reporting excision of the temporal lobe for psychomotor epilepsy but without any intellectual test results are those of German (1939), Furlow (1938), Penfield and Flanigin (1950), and Obrador (1953).

So far as can be discovered, only two studies specifically report test changes following temporal lobectomy. One is by Hebb (1939), who reported on a man aged 30 with post-traumatic epilepsy, most of whose right temporal lobe was removed. He showed that, while intelligence, as measured by a standardized intelligence test (the Binet), apparently remained high after the operation, nevertheless the patient performed very poorly on certain other intellectual tasks of a non-verbal nature, and he concluded that a single over-all score (such as the Binet I.Q.) could result in misleading conclusions. This study is of

importance in so far as it indicates the danger of concluding that the patient is unimpaired following the operation if the I.Q. level is unchanged—a point which the present paper will also demonstrate.

Milner (1954) has briefly indicated the results of an unpublished study of intellectual changes following temporal lobectomy for relief of focal epilepsy caused by atrophic lesions of the cortex. She studied 25 cases submitted to the operation (13 right temporal and 12 left temporal, together with 13 frontal and parietal cases as controls). A battery of 16 tests was given pre-operatively and three weeks post-operatively. The experimental and control groups were well matched with respect to age, vocabulary, and occupational status. The temporal lobe group as a whole was inferior to the controls, both before and following the operation, on two visual tests involving complex picture material. The right temporal lobe group was inferior to the other groups on tests of spatial patterning, both visual and tactual, the deficit being present before the operation but intensified afterwards. While these results seem to be of considerable importance, it is impossible to evaluate them in the absence of published data.

Since the present paper is principally concerned to demonstrate that a gross learning deficit may exist following the operation, it is interesting to note that such a learning deficit has been reported by a number of authors. Such studies, however, suffer from two severe defects : in the first place interpretation of the results is often complicated by the existence of a tumour of the temporal lobe, while in the second place the reports are usually of a clinical nature with little or no attention paid to statistical evaluation of the results. Hence, the observations and conclusions of these authors, while affording valuable hints and leads, cannot be accepted as they stand but require confirmation by properly controlled experiments.

Thus Fox and German (1935) reported the results of temporal lobectomy in a case of a large astroblastoma in the anterior portion of the temporal lobe. They reported that " retention of auditory material was definitely inferior to that of visual experience. The patient was unable to repeat a series of more than two unrelated words or numbers ". On the other hand, " the patient appeared to be of average intelligence, and with the exception of the speech difficulty no intellectual defect resulted ". This study is unsatisfactory because no proper controls were employed in the evaluation of the results.

A similar criticism may be made of the paper by Kolodny (1928), who studied 38 cases of temporal lobe tumour and found that " in 19 patients out of the 38 in this series there was definite subjective, or subjective and objective, evidence of deterioration of memory ". However, he concluded that " probably patients with organic lesions of the brain fail to fix or register an impression rather than forget a duly registered one ", i.e., the defect was one of learning rather than retention. A similar conclusion was reached by Keschner, Bender, and Strauss (1936). In a series of 110 cases of temporal lobe tumour they found disturbances in memory and orientation in 55 cases. After a careful discussion of the various phases of " memory " they concluded that in their cases the defect lay primarily in the " impression " or learning phase. " Recent events and sensory stimuli either do not enter consciousness or, if they do enter it, do not make a psychic impression of sufficient intensity to be recalled, i.e., amnesia occurs by faulty fixation."

This brief review of the literature indicates that, while a number of interesting leads may be gained from its perusal, it is impossible to draw any definite conclusions with regard to intelligence and learning following the operation. In most instances there is simply a lack of the basic data required for such an evaluation, for example, details of test results, intervals between testing pre- and post-operatively, control of intelligence, and so on. In this connexion reference may be made to the important article by Hebb (1945). He pointed out, for instance, that it is frequently assumed (especially where unstandardized tests are used) that the task is so simple that a person of normal intelligence would have no difficulty in completing it, whereas this assumption may in fact be completely incorrect. This error is very common where only clinical estimates are made of the patient's ability following the operation, especially in cases where no pre-operative testing has been carried out. It is for this reason that the literature reviewed above must be considered inconclusive.

The Sample of Patients and Operative Technique

Results on a total of 18 patients are reported in this paper. Of these 18 patients, 12 were tested by the present authors, while the results on the remaining six were abstracted from previous clinical test results.*

Table I describes the 18 patients in terms of age, sex, location of epileptic foci, duration of fits before operation, and history of trauma.

There are 11 cases where surgery took place on the dominant hemisphere, six cases of operation on the non-dominant hemisphere, and one doubtful case. This information was abstracted from the case notes

* These six patients were tested by Miss Shelagh Cox, now senior clinical psychologist, Westminster Hospital.

TABLE I
DESCRIPTION OF PATIENTS

No.	Sex	Age	Dominant or Non-dominant Hemisphere	Duration of Fits (years)	E.E.G. Evidence	History of Trauma
1	F	43	Dominant	12	L. temporal	—
2	F	25	,,	14	L. temporal	Possibly at birth
3	M	39	,,	15	L. temporal	—
4	F	22	,,	19	L. temporal	Age 6
5	F	17	,,	7	R. temporal focus	—
6	F	20	,,	7	L. anterior temporal	—
7	M	32	,,	15	L. anterior inferior temporal	Yes. Age unknown
8	M	42	,,	5	L. temporal	—
9	M	21	Non-dominant	21	R. temporal pole	—
10	F	27	,,	9	R. anterior temporal	—
11	M	23	Dominant	3	L. temporal focus	Age 20
12	M	48	,,	8	L. temporal focus	—
13*	M	45	Non-dominant	23	R. temporal	Age 27
14*	M	45	,,	43	R. temporal	Age 2 (dubious)
15*	M	23	,,	11	R. temporal	—
16*	F	15	,,	7	R. temporal focus	—
17*	M	31	Dominant	29	L. anterior inferior temporal	—
18*	M	25	Doubtful	7	R. temporal pole; occasional L. temporal	—

*Tested by Miss Shelagh Cox.

and was therefore quite independent of the psychological test results, being based on neurological and other data.

The operative technique has been fully described by Falconer (1953).

> "Starting at the Sylvian point, the incision ran backwards through the upper part of the superior temporal convolution to the foot of the Rolandic fissure, and then it curved downwards to reach the inferior border of the temporal lobe, a little in front of Labbé's anastomotic vein. Then the incision was steadily deepened to expose above and anteriorly the insula and the upper bank of the Sylvian fissure still covered by the pial mantle of the temporal operculum and posteriorly to open the hinder part of the temporal horn. Next the white matter was divided between the lower boundary of the insula and the temporal horn, thus laying open the temporal horn with the hippocampus in its floor and the choroid plexus above this. The removal of the lobe was then completed by continuing the incision across the hinder end of the hippocampus on to its medial border, as well as along the medial border of the uncus . . . our operative removals involved between 5 cm. and 9 cm. of the length of the temporal lobe."

The Tests

At different times a large number of tests have been used in the investigation of these patients. For the purposes of this paper, however, the test results to be reported fall clearly into three groups. The tests were given with the intention of measuring clinically changes in intelligence, learning, and retention following the operation.

Tests of Intelligence.—The tests falling under this heading were :

Wechsler-Bellevue Intelligence Scale (*Wechsler*, 1944).—This is a composite intelligence test, comprising five "performance" sub-tests and six "verbal" sub-tests and yielding a performance scale I.Q., a verbal scale I.Q., and a full-scale I.Q. The information sub-test was omitted (since it is unsuitably constructed for English subjects) and replaced by the vocabulary sub-test. Form I was administered pre-operatively, Form II post-operatively.

Mill Hill Vocabulary Test (*Raven*, 1948).—This is a verbal test assessing vocabulary level, and is given in two parts : synonyms (in which the patient underlines the correct word from a choice of six words) and definitions (in which the patient writes out the meaning of the words). Form I was administered pre-operatively and Form II post-operatively.

Raven's Progressive Matrices (*Raven*, 1949).—This is a non-verbal test of intelligence. For normal subjects, the spatial factor involved in this test does not seem to affect the results and the test is therefore usually regarded as a good measure of general intelligence. It is, however, quite possible that the spatial factor would be important for the patients in the present study, especially following the operation, since some of them suffered from visual difficulties. Thus it was not possible to say beforehand whether this test would serve as a good measure of general intelligence unaffected by specific disabilities following the operation.*

The Nufferno Speed and Level Tests.—These tests are not in general use and will be briefly described.

The Level Test consists of items of increasing levels of difficulty (determined empirically) made up of series of letters followed by a dot. The subject's task is to discover the principle involved in each series and supply the missing letter. Thus in the series : A A B B C C D . the missing item would be D. Ample time is allowed the subject, who is instructed to work at his own speed. The same form was used for test-retest.

The Speed Test consists of a similar series of items, of a very much simpler nature, however, such that most subjects find the task well within their capabilities. The test can be given in two forms : unstressed (where the subject is allowed to work at his own pace) and stressed (where he is instructed to work as quickly as possible, the speed element being emphasized). The score on this test is the number of items correctly completed. Equivalent forms are available for both stressed and unstressed versions of the test.

* For the Mill Hill and Matrices tests the raw scores were transformed into equivalent I.Q.s (with a mean of 100 and S.D. of 16) in order to be more readily comparable with results on the other tests of intelligence.

Tests of Learning and Retention.—The process of "memory" is commonly divided into three sections: the phase of acquisition of material (the "learning" phase), the phase of retention, and the phase of reproduction or recognition. This division is of course artificial since all learning involves retention. It is customary to speak about learning when a short time elapses between acquisition and reproduction, and about retention when the interval is longer. Before retention proper can be tested adequately, it is important that learning to a criterion be established in order that differences in rate of learning may be controlled.

New Word Learning and Retention Test (*Nelson*, 1953).—In this test the subject is first given a vocabulary test in the usual way (Binet is used pre-operatively, Wechsler post-operatively) until five consecutive words are failed. The subject is then required to learn the meaning of these five unfamiliar words until he has given three successful definitions—not necessarily three consecutive successful definitions. The definitions given to the subject are taken from Binet's and Wechsler's forms, and are changed at each presentation to avoid rote learning. It was known (Nelson, 1953) that normal subjects learned in five trials, i.e., required only one definition for each word in order to learn the meaning of it. Since these nouns were derived from a single testing on the Binet and in this investigation the Wechsler was used post-operatively, it was necessary to show that the Binet and Wechsler were reasonably comparable in this respect. This was done by testing six cases of temporal lobe epilepsy (not suitable for operation) on the vocabulary test of the Binet and then on the Wechsler three weeks later. Only one of these patients required more definitions (two) on retest, while one required five fewer definitions to learn to the criterion. The remainder made no errors at both sessions. Thus the Binet and Wechsler vocabulary sub-tests may be considered roughly equivalent for this type of patient.

Paired Associate Learning and Retention Test.—This test, taken from the Wechsler Memory Scale (Wechsler, 1945), involves the learning of 10 pairs of words: six easy associations, e.g., north–south, and four difficult, e.g., in–although. The examiner first presents the 10 pairs, then repeats (in a new order) the 10 initial words of each pair, the subject being required to reproduce its associate. If an error is made, it is corrected. In the Wechsler Memory Scale the procedure is repeated three times in all, giving a maximum possible score of 18 easy associations and 12 difficult ones. For the present work, a further three random presentations were constructed. The score was the number of easy and difficult associations correctly reproduced on the final trial.

Two equivalent forms of the test are available, which Stone, Girdner, and Albrecht (1946) considered to be well matched for difficulty level.

Tests of Retention.—Some attempt was made to measure retention in the following way:—

The subject was tested on the New Word Learning and Retention Test 24 hours following the learning period and was simply asked to define the five words previously given. The score was the number of words correctly defined.

Similarly the subject was given one further presentation of the Paired Associate Learning and Retention Test 24 hours following the learning period and the score on easy and hard associations noted.

A short test of memory for recent and remote events was added, consisting of a list of questions related to the past life and recent history of the patient.

The pre-operative testing was carried out about two to seven days before the operation. Post-operative testing took place 21 to 28 days following the operation. In some instances further testing has been carried out 12 months after the operation.

Results

Intelligence Tests: Pre-operative Level.—For the patients tested before operation on the Wechsler, the mean full-scale Wechsler I.Q. was 97·72 (range 67–120, 18 cases).* This value compares well with recent findings on epileptics living outside institutions whose mean I.Q. has been shown to be about the same as the mean I.Q. of a sample from the general population (Collins, 1951; Folsom, 1953). The pre-operative findings on the verbal and non-verbal tests may be compared with those of Rey, Pond, and Evans (1949), who found that their epileptoid and epileptic patients tended to score lower on the verbal when compared with the performance scale of the Wechsler and to score lower on the Mill Hill Vocabulary Scale than on Raven's Matrices. For the present group, the mean performance scale I.Q. for 16 cases was 97·88, while the mean verbal scale I.Q. was 94·38. For 11 cases, the mean Matrices I.Q. was 96·73 and the mean Mill Hill I.Q. 88·00. Although both differences are in the same direction as those found by Rey, Pond, and Evans, neither reaches statistical significance. On the Wechsler, a number of large differences in the opposite direction were observed; on the Mill Hill and Matrices, the Mill Hill score was considerably larger than that on the Matrices in only one case. On the whole, therefore, the present group of subjects may be considered substantially similar to the epileptoid and epileptic patients described by Rey, Pond, and Evans.

Intelligence Tests: Post-operative Level.—Intelligence was tested by the following:

Wechsler Intelligence Scale.—Comparisons were available for nine dominant hemisphere cases. The post-operative changes are shown in Table II. The mean full-scale I.Q. fell from 92·67 to 84·44, the difference being significant at the 0·05 level ($t = 2·218$); the mean performance scale I.Q. fell from

* In two cases the Wechsler full-scale I.Q. was calculated *pro rata* on the basis of three sub-tests.

TABLE II
RESULTS ON WECHSLER INTELLIGENCE SCALE

Subject	Performance Scale		Verbal Scale		Full Scale	
	Pre	Post	Pre	Post	Pre	Post
Dominant						
1	99	102	104	104	101	103
2	81	56	101	69	91	60
3	121	108	102	95	112	100
4	72	67	69	74	67	68
5	78	78	76	76	74	72
6	84	63	77	70	79	64
7	124	117	104	102	115	110
8	123	104	107	96	116	101
17	74	84	86	82	79	82
Means ..	95·11	86·56	91·78	85·33	92·67	84·44
Non-dominant						
9	100	96	87	87	93	91
10	126	116	113	113	120	115
13	115	107	108	10)	112	106
14	105	104	99	91	102	96
16	74	87	87	93	79	89
Means ..	104·00	102·00	98·80	98·60	101·20	99·40

95·11 to 86·56, the difference being significant at the 0·05 level (t = 2·170); the mean verbal scale I.Q. fell from 91·78 to 85·33, the difference not quite attaining significance (t = 1·809). Inspection of the changes in Table II shows that some of the differences following operation can be accounted for in terms of the very poor performance of a few patients following the operation. In these instances the fall can be explained on the grounds of specific visual and/or verbal difficulties which were not present before the operation. Thus, on the performance scale, these patients complained of the difficulty of perceiving small details and had to turn their heads sideways or cover one eye to see clearly. The one patient who showed a severe drop on the verbal scale (No. 2) suffered from severe expressive aphasia following operation.

When the changes on sub-test scores for these dominant cases were examined (Table III) it was

TABLE III
MEAN CHANGE IN WEIGHTED SCORE AFTER OPERATION ON 10 SUB-TESTS OF WECHSLER INTELLIGENCE SCALE

Sub-test	Dominant (N=9)	Non-dominant (N=3)
1. Comprehension	−1·89	−0·67
2. Arithmetic	−1·11	−3·00
3. Digit span	−0·89	+0·67
4. Similarities	−1·11	−0·67
5. Vocabulary	−1·00	+0·67
6. Picture arrangement	−1·78	+0·67
7. Picture completion	−0·8)	+1·00
8. Block design	−0·89	−2·00
9. Object assembly	−1·00	−0·33
10. Digit symbol	−1·22	−3·33

seen that, for all 10 sub-tests, the mean change in weighted score was negative, i.e., there was a slight but very consistent tendency for these patients to decline on all the sub-tests of the Wechsler. It is very difficult to interpret this finding, since adequate data on changes from Form I to Form II of the Wechsler are not available. The change, for instance, may be due to differences in standardization, or it may represent a genuine small general decline in ability following the operation.

The five non-dominant cases, on the other hand, showed no significant change on the Wechsler as a group, nor were there any large individual changes. Furthermore, there was no consistent pattern of change on the sub-tests, six showing a mean decline and four a mean increase.

Thus, we may conclude that on the Wechsler the dominant cases show a significant fall in full-scale I.Q.; that in some individuals the drop may be severe; but that there appears to be a general tendency for scores to fall slightly on all sub-tests. For the non-dominant cases no such decline is apparent.

TABLE IV
RESULTS ON MATRICES AND MILL HILL VOCABULARY TESTS

Subject	Matrices		Mill Hill	
	Pre	Post	Pre	Post
Dominant				
2	86	87	91	86
3	109	109	87	89
4	81	76	82	83
5	77	84	75	76
6	79	81	82	80
7	111	112	89	86
8	118	119	90	81
11	111	117	—	—
12	100	98	—	—
Means	96·89	98·11	85·14	83·00
Non-dominant				
9	85	86	83	83
10	119	119	95	95
15	113	115	—	—
Means	105·67	106·67	89·00	89·00
Doubtful				
18	86	83	102	96
Mean of all cases	98·08	98·92	87·60	85·50

Mill Hill Vocabulary Test.—Pre- and post-operative results are available for seven dominant patients (Table IV); the respective means are 85·14 (pre-operative) and 83·00 (post-operative), the difference not being statistically significant. Both non-dominant cases obtained identical scores on test-retest. These results are similar therefore to those obtained on the Wechsler Verbal Scale I.Q. in indicating a slight fall in verbal intelligence, which might, however, be due to chance fluctuations.

Progressive Matrices.—As has been pointed out already, it was not known whether the spatial factor in this test would become prominent following the operation. However, the results for 13 subjects

(nine dominant, three non-dominant, one doubtful) indicate clearly that the intellectual level, as measured by this test, does not change as a result of temporal lobectomy. The results are shown in Table IV. The pre-operative mean for all 13 cases was 98·08, the post-operative mean 98·92, the difference not being significant. For the nine dominant cases, the pre-operative mean was 96·89, the post-operative mean 98·11, the three non-dominant cases showing no change. It was interesting to note, however, that all the dominant cases, with one exception, took longer to complete the test after the operation than before. This was probably related to the visual difficulties many of them suffered from.

Speed and Level Tests.—Results on the Level Test are available for only five dominant cases, which showed a mean decline from + 0·10 σ pre-operatively to − 0·23 σ post-operatively, the difference not being significant (Table V). In none of these cases was the score improved. On the Unstressed Speed Test there was a mean decline from − 0·15 σ to − 0·23 σ (four cases), individual changes being very small. Only two dominant cases were given the Stressed Speed Test. The two non-dominant cases, who were given all three tests, showed no consistent changes.

TABLE V
RESULTS ON THE LEVEL AND SPEED TESTS*

Subject	Level		Unstressed Speed		Stressed Speed	
	Pre	Post	Pre	Post	Pre	Post
Dominant						
2	+0·93	−0·29	0·00	+0·09	Not given	
5	−0·75	−0·92	−0·55	−0·73	Not given	
6	−1·30	−1·30	Results unreliable			
7	+0·70	+0·44	+0·04	+0·04	+0·99	+0·60
8	+0·94	+0·94	−0·09	−0·33	+0·12	+0·26
Means ..	+0·10	−0·23	−0·15	−0·23	+0·56	+0·43
Non-dominant						
9	+0·68	+0·68	−0·26	−0·32	+0·15	+0·28
10	+1·90	+2·20	+0·56	+0·15	+1·70	+0·45
Means ..	+1·29	+1·44	+0·15	+0·09	+0·93	+0·37

*Scores are given as standard scores in relation to the standardization population of this test.

The possible effects of practice on the post-operative results have been considered. It is known that retesting on the Wechsler Intelligence Scale, using Form II, tends to lead to a slightly lower score, rather than a higher one (Gerboth, 1950), though his study was carried out on normal subjects of superior intelligence, i.e., practice effects are negligible. Eysenck (1944) has shown that the average gain in raw score points for normal persons on retest on the Matrices is 3·73, for neurotics 1·96. The mean raw score increase for the 13 cases tested pre- and post-operatively in this study was 1·00; for the nine dominant cases 1·29. So far as is known, no data are available showing the mean raw score change on the Mill Hill Vocabulary Test. There seems no reason, therefore, to suppose that the results reported in this paper are distorted by hidden practice effects.

TABLE VI
RESULTS ON NEW WORD LEARNING AND RETENTION TEST

Subject	No. of Definitions Required to Produce Three Successful Definitions of Five Words	
	Pre	Post
Dominant		
3	14	23
4	6	11
5	14	35
6	12	56
7	7	44
8	11	79
Means	10·67	41·33
Non-dominant		
9	8	6
10	5	5
Means	6·5	5·5

Learning Tests.—The same tests were used as before operation.

New Word Learning and Retention Test.—The results on this test are shown in Table VI. Although results pre- and post-operatively are available for only six dominant patients, the results are very striking. An average of 10·67 trials was required before operation, compared with an average of 41·33 trials following it. Despite the small number of cases, the difference was statistically significant at the 0·01 level (t = 3·155). All of the patients performed at a lower level following the operation, and in some patients performance was extremely poor. It must be remembered that the criterion of success-

TABLE VII
RESULTS ON PAIRED ASSOCIATES LEARNING AND RETENTION TEST

Subject	No. of Associations Correct on Final Trial			
	Easy		Difficult	
	Pre	Post	Pre	Post
Dominant				
4	6	5	4	1
5	5	5	2	0
6	6	2	1	0
7	6	4	4	0
8	5	4	4	0
12	6	5	3	0
Means ..	5·67	4·17	3·00	0·17
Non-dominant				
9	6	6	4	4
10	6	6	4	4
Means ..	6	6	4	4

ful learning was not three successive accurate definitions but three at any time during learning. There is no doubt but that the former criterion would have been an impossible one for some of the patients to reach. These results become even more striking when compared with those for the two non-dominant patients, who showed no such disability following the operation.

On this test, therefore, cases whose operation was on the dominant side all showed gross difficulty in learning following operation, but there is some evidence that such disability does not occur when the operation is on the non-dominant side. It is noteworthy that before operation the dominant cases had a significantly lower level of learning efficiency on this test compared with normal subjects, the deficit being intensified following the operation.

Paired Associates Learning and Retention Test.—Table VII shows the results on this test for six dominant cases and two non-dominant cases. With respect to difficult associations, the dominant group shows a decline from a mean of 3·00 correct responses pre-operatively on the final trial to a mean of 0·17 correct responses post-operatively, the difference being highly significant at the 0·001 level ($t = 5·896$). On the easy associations, there is a drop for these patients from a mean of 5·67 correct responses pre-operatively to a mean of 4·17 correct responses post-operatively, this difference being significant at the 0·03 level ($t = 2·680$). Five of the six dominant patients were completely unable to learn difficult associations following the operation. One other patient (No. 11), who was not given this test pre-operatively, was equally unable to learn difficult associations following the operation, obtaining 11 out of 18 easy associations correct, but only one out of 12 difficult associations. (His pre-operative I.Q. was above average.) Neither of the two non-dominant cases showed any decline on easy or difficult associations following the operation. The results of these two tests, therefore, indicate that a marked deficit in the learning of verbal associations may occur as a result of temporal lobectomy. The learning deficit applies both to new and unfamiliar material and to easy associations, and seems to be particularly evident when the operation is performed on the dominant hemisphere.

The qualitative behaviour of some of those patients who dropped sharply on the Learning Test was strikingly different from what it was before operation. After operation they appeared baffled and frustrated by the Paired Associates Test and did not show any idea of how to cope efficiently with the material. They might seize on a single word and repeat it each time until eventually a correct response was obtained by chance. The performances were marked by a trial and error approach and perseveration was common. On the other hand one patient who learned easy associations without undue difficulty after the operation seemed simply unable to learn the difficult associations but did not become ruffled or annoyed; rather he did not seem aware of the drop in performance. Other patients were very much aware of their deficit and became increasingly upset by it.

Retention Test.—Since learning was not carried out to a wholly acceptable criterion, the results on the Retention Test should be regarded with caution. Table VIII shows the results on the New Word Learning and Retention Test 24 hours after original learning.* In spite of the small number of subjects, the difference between pre- and post-operative retention is significant at the 0·001 level ($t = 4·255$) for the dominant cases. Neither of the two non-dominant cases showed any defect after 24 hours.

TABLE VIII
RETENTION AFTER 24 HOURS

Subject	New Word Learning and Retention Test	
	Pre	Post
Dominant		
3	5	1
4	5	3
5	3	3
6	2	1
7	5	2
8	4	1
Means	4·00	1·83
Non-dominant		
9	5	5
10	5	5
Means	5	5

Retest After One Year

To date it has been possible to retest four of the original patients at longer intervals following the operation. The results of such testing are shown in Table IX. The results of these patients will be considered separately. They are all dominant cases.

Patient No. 3, who showed a drop of 13 points on the performance scale of the Wechsler three weeks after operation, had recovered to his former level after one year. On the New Word Learning and Retention Test, however, he required 26 definitions after one year, compared with 14 pre-operatively and 23 three weeks post-operatively, i.e., his learning ability was still impaired.

* Results for the Paired Associates Test are not shown, since most of the dominant cases failed to attain perfect learning at the end of six trials following the operation. Hence their pre- and post-operative retention scores were not comparable. Results are also not shown for the third retention measure since it was not quantified.

Patient No. 4 showed no changes in intelligence as estimated by the Wechsler three weeks and one year post-operatively, but required 14 definitions after one year compared with six pre-operatively and 11 post-operatively, i.e., her learning was still impaired.

Patient No. 11 showed a progressive increase in the Matrices I.Q. three weeks and three months post-operatively (probably a practice effect), but

TABLE IX
RESULTS ON RETEST AFTER 12 MONTHS

Wechsler

Subject	Performance Scale			Verbal Scale			Full Scale		
	Pre	3 wk. Post	12 m. Post	Pre	3 wk. Post	12 m. Post	Pre	3 wk. Post	12 m. Post
3	121	108	121	102	95	101	112	100	111
4	72	67	76	69	74	66	67	68	68
12	—	—	99	—	—	101	112*	107*	99

Matrices and Mill Hill

Subject	Matrices				Mill Hill		
	Pre	3 wk. Post	3 m. Post	12 m. Post	Pre	3 wk. Post	12 m. Post
3	109	109	—	—	87	89	—
4	81	76	—	81	82	83	81
11	111	117	126	—	—	—	—
12	100	98	—	—	—	—	—

New Word Learning and Retention Test

Subject	Number of Definitions Required		
	Pre	3 wk. Post	12 m. Post
3	14	23	26
4	6	11	14

Paired Associates Learning and Retention Test

Subject	Number of Correct Associations on Final Trial							
	Easy (maximum 6)				Difficult (maximum 4)			
	Pre	3 wk Post	3 m. Post	12 m. Post	Pre	3 wk. Post	3 m. Post	12 m. Post
11	—	3	3	2	—	0	0	1
12	6	5	—	6	4	0	—	1

*Indicates that the full-scale I.Q. was based on the results of three sub-tests only.

was entirely unable to learn difficult associations 12 months after the operation although he was in fact at this time being given a form he had already attempted before. His solitary success on this task was due to chance, i.e., he repeated the same association each time in the series until the correct antecedent presented itself. Thus he exhibited a striking learning deficit a full year after the operation.

Patient No. 12 showed no change in intelligence following the operation or after an interval of a year. This patient achieved some success with difficult associations before the operation, but was completely unsuccessful after the operation although the original series was being used after 12 months. He too showed a gross learning deficit.

Thus it is clear that four patients tested one year after the operation, although showing no deficit on the standard intelligence tests, were uniformly incapable of learning unfamiliar verbal-auditory material. This defect was the more striking in that two of the four patients were attempting to deal with material which was identical with that which had been presented to them before operation and which they had at that stage evinced less or no difficulty in learning.

Discussion and Conclusions

The conclusions to be drawn from the above investigations must necessarily be considered to be tentative in view of the small numbers of patients involved.

Changes in Intellectual Status.—The results obtained on the Wechsler, Matrices, and Mill Hill tests suggest that for the dominant cases there may be a slight general decrease in scores on intelligence measures making use of verbal or performance material, but that such a decline is not manifested on the Raven's Matrices Test. The possible long-term effects of the operation are of course unknown. For the non-dominant cases the operation appears to have no immediate effect on intellectual functioning. Some dominant cases do show large drops on the Wechsler, and these would seem to be due to specific disabilities, since these patients show no such drop on the Matrices, and such defects, when they occur, are probably temporary. One patient showing such a decline after the operation had recovered to his former level when tested a year later.

Learning Ability.—There is evidence that a severe impairment of the ability to learn new associations or the meaning of new words is a usual sequel to the operation. This impairment is found in the learning of both simple and complex material.

There is evidence that the learning impairment takes place when the operation is carried out on the dominant hemisphere, but does not result when the operation is on the non-dominant side. While the former case seems well established, the evidence for the latter is only suggestive and further study is essential.

There is some evidence that the learning impairment present after the operation may persist to the

same degree of severity at least one year following the operation. All four cases so far tested one year after operation have shown no improvement in this respect.

There is no evidence that the learning tasks are too difficult for the patients, since they served as their own controls before the operation.

There is no evidence to show that failure to learn following the operation is correlated with intelligence level as measured by the Matrices Test. For the dominant cases, rank order correlations between scores on the New Word Learning and Retention Test and measures of intelligence (Wechsler full-scale I.Q. or Matrices I.Q.) yielded insignificant values of ρ both before and after the operation.

There is a small amount of evidence that retention may be impaired following the operation on the dominant side, but the numbers involved are very small and learning to a satisfactory criterion was not established.

The possibility arises of course that the ability to learn on the New Word Learning Test was affected by the fact that most of the dominant cases were suffering from aphasic difficulties following the operation. Three points may be made in this connexion :—

In the first place, the aphasic difficulties do not account satisfactorily for the difficulties on the Paired Associates Test. On this test, the patients frequently responded with the incorrect association. If aphasic difficulties alone were operating, the patient would be unable to find the correct word, rather than give an incorrect one.

In the second place, of the six patients showing decline on the New Word Learning Test, four showed an increase of 1 weighted point on the Wechsler vocabulary sub-test following the operation ; one dropped by 1 point and one by 3 points. The aphasic difficulties therefore did not lead to any marked difficulty in defining known words ; the difficulty lay in learning the meaning of new words.

None of the four patients tested a year after the operation showed any but the slightest signs of aphasic difficulties ; yet all four still showed a striking deficit in learning ability.

It would of course be entirely premature to attempt to generalize from these limited findings to learning ability in other modalities. A further experimental investigation is at present being carried out in which aphasic difficulties will be controlled to determine the precise role they play in the post-operative fall in this kind of learning ability. A number of modalities will be investigated, including the visual, kinaesthetic, and auditory, using different types of material.

Summary

Testing of patients undergoing temporal lobectomy for psychomotor epilepsy suggests that following the operation :

(1) General intelligence is relatively unimpaired.

(2) Specific abilities may be impaired, at least for some time.

(3) A significant learning disability may result.

(4) The disability is strongly associated with lesions of the dominant hemisphere.

(5) The disability may still be present a year after operation.

(6) The learning disability is not a function of the level of intelligence of the patient or of intellectual changes following operation.

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