INTELLECTUAL EFFECTS OF TEMPORAL-LOBE DAMAGE IN MAN

by

BRENDA MILNER

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The clinical literature on the intellectual effects of human brain damage reveals a constant preoccupation with the problem of the role of the frontal lobes, with a corresponding neglect of other parts of the cerebral cortex. In particular there is not a single systematic investigation of the effects of temporal-lobe damage in man, although there are several isolated and highly suggestive reports of individual cases. Fortunately the situation is quite different with regard to animal work, where the last few years have yielded numerous reports dealing with the effects of temporal-lobe lesions of varying extent on the learning ability of lower primates. This material is highly relevant to the present investigation, since it draws attention to types of deficit which might well be found at the human level also, but which have been neglected; for this reason the animal data will be presented in some detail, before passing to a review of the clinical literature.

Since the present study deals only with cognitive functions, there will be no detailed discussion of the emotional changes often seen in temporal-lobe damage. In the monkey, a decrease in emotional reactivity regularly follows deep-temporal removals (Brown and Schafer, 1888; Kluver and Bucy, 1938; Bard, 1950; Thomson and Walker, 1951; Mishkin, 1951; Poirier, 1952); in man, electrographic abnormality in the anterior temporal region frequently gives rise to personality disturbances (Bailey and Gibbs, 1949), and ablation of the temporal tips may cause extreme docility (Green, Duisburg and McGrath, 1951). It is now believed that such phenomena depend largely on damage to the amygdala, as removal of this area in animals has striking, though inconsistent, emotional effects, causing savageness in the cat (Spiegel, Miller and Oppenheimer, 1940; Bard and Mountcastle, 1948), and tameness in the monkey (as seen in the studies mentioned above). Gastaut (1952) reports rage responses with stimulation of the amygdala in waking cats, and in the same article admirably reviews what is at present known about the complex anatomical structure and rich connections of this important area. This literature has also been surveyed by McLean (1949), but with theoretical speculations which seem more elaborate than the data warrant.

REVIEW OF ANIMAL STUDIES

The cognitive effects of temporal-lobe damage have been most clearly demonstrated in animal studies. A series of careful ablation experiments on the posterior cortex of the monkey has shown conclusively that the temporal lobes have important visual functions, and indeed that a major extra-striate focus for vision is to be found in this region. The experimental evidence also suggests that the temporal lobes play an appreciable, though minor, role in tactual discrimination.

Vision in Monkey after Removal of the Temporal Lobes

The first evidence that temporal-lobe lesions affect visual functions appears in the work of Sanger Brown and Schafer (1888), who reported gross, though transient, disturbance of visual object recognition in monkeys, following removal of the temporal lobes. However, the importance of this finding does not seem to have been realised at the time, and no formal testing was done. Recent interest in the topic stems from Kluver and Bucy's dramatic demonstration in 1938 that destruction of the temporal lobes in the macaque brings about a state of "psychic blindness", which they believed to be similar to that of visual agnosia in man. Their animals no longer discriminated between edible and inedible objects, nor between neutral and previously fear-provoking ones, and were markedly handicapped on tests of form discrimination; yet these disturbances could not be attributed to sensory loss, since the animals showed only slight upper-quadrant field defects, and were abnormally reactive, rather than unresponsive, to visual stimuli.

One interpretation of these results attributes the deficit to accidental damage to area 19 (Fulton, 1943), areas 18 and 19 being traditionally regarded as the visual association area, the seat of higher visual functions. However, the evidence is strongly against such an interpretation. Attempts to duplicate Kluver and Bucy's findings by extensive lesions within the prestriate region have failed. Large selective ablations of either the lateral or the mesial surfaces of areas 18 and 19 can be made with only slight visual disturbance (Lashley, 1948; Chow, 1951); and it has been claimed that destruction of all but the inaccessible posterior ventromedial sector of the prestriate region only retards visual learning in so far as the animal may have to adjust to an excessively restricted visual field (Chow, 1952). As against these negative findings, the evidence for visual deficit following prestriate ablation is meagre and internally inconsistent: Chow (1951, 1952) and Lashley (1948) fail to confirm Ades' (1946) report of amnesia for visual habits following one-stage bilateral prestriate ablation; Lashley's own finding of deficit on a visual conditional reaction has not been corroborated by Chow (1952); while disturbance of object recognition in the first few post-operative days was seen by Chow but not by Lashley. According to Riopelle and Ades (unpublished study, cited by Riopelle, Harlow, Settlage and Ades, 1951) there may be transient retardation of new learning, but there is no residual deficit. It is clear that the picture of mild, transient, and variable disturbance which emerges from these studies discredits the traditional view that the prestriate cortex is the major visual association area. Coupled with Kluver and Bucy's findings, it directs attention to the temporal lobes as a probable extra-striate focus of visual functions.

Kluver and Bucy's temporal-lobe extirpations were large, and included the hippocampus and amygdaloid complex bilaterally, sparing only the primary auditory area (and most of the optic radiations). Later work has confirmed that such extensive damage to temporal neocortex and allocortex suffices to cause profound visual disturbance, even though care is taken not to invade the prestriate region (Blum, Chow, and Pribram, 1950; Mishkin, 1951; Riopelle and Ades, 1951; Poirier, 1952). The disturbance has tended however to be less dramatic than that described by Kluver and Bucy, and only Mishkin has reported persistent loss of object recognition, which is of course the essential feature of visual agnosia in man. In formal testing situations all animals show impairment on a variety of visual discrimination problems after removal of the temporal lobes; the deficit is apt to be particularly severe on tests of pattern discrimination but there may also be disturbance of colour (Blum, Chow and Pribram, 1950; Chow, 1951; Mishkin, 1951), and even of brightness discrimination (Chow, 1951; Mishkin, 1951).

When attempting to evaluate the effects of temporal-lobe lesions, two points should be emphasised. First, the behavioral changes cannot be attributed to the slight and variable visual field defects that have been found, since much greater field defects occur after parietal-cortex removal, but without producing such disturbance (Blum, Chow, and Pribram, 1950); the same is true in the case of extensive sub-total damage to the striate cortex (Kluver, 1937; Harlow, 1939; Settlage, 1939). Secondly, the effects cannot be attributed to general intellectual deficit. The attempt to limit visual functions to the striate cortex, while ascribing visual deficits seen with extra-striate lesions to a non-specific loss (Lashley, 1950), simply does not fit the facts. An animal may succeed on auditory or somaesthetic problems at a time when it shows severe visual loss, and there is evidence that temporal lobe damage need not prevent good performance on delayed-reaction problems (Jacobsen and Elder, 1936; Mishkin, 1951), although in some cases it apparently does (Blum, Chow, and Pribram, 1950). Thus we are forced to conclude that temporal-lobe ablation has a selectively detrimental effect on visual learning and retention.

This deficit is hard to define. A visual disturbance which affects brightness, colour, and pattern discrimination, while leaving object recognition and visual acuity intact, cuts across the classical distinction between complex "associative" functions and simpler sensory ones, and thus lends support to those who, on the basis of systematic studies of human brain damage, doubt the existence of pure disorders of visual integration (Bender and Teuber, 1949; Bay, 1950). It has been pointed out that we cannot decide intuitively what constitutes a simple, and what a complex visual task (Chow, 1951; Mishkin, 1951). Mishkin finds, and Riopelle and Ades (1951) agree, that, other things being equal, the degree of retardation seen on a series of visual tasks after temporal-lobe ablation varies directly with the difficulty of such tasks for the intact animal, and that in this sense, and in this sense only, it can be said that complex visual tasks are more affected than simple ones.

Visual Localisation within the Temporal Lobe (Monkey)

The question next arises as to whether a comparably severe visual disturbance may be produced by smaller lesions within the massive temporal cortex, or whether the only important factor is the amount of temporal-lobe tissue destroyed.

Reviewing the literature with respect to the lateral surface, we find some inconsistencies. Kluver and Bucy (1939) emphasise the lack of gross visual disturbance following bilateral removal of either the first, second, or third temporal convolutions, and Ades and Raab (1949) report that damage to the lateral surface had no effect on a learned pattern discrimination (they do not report the extent of the damage). Similarly, Mishkin (1951) presents essentially negative results from lateral-surface extirpations, although he finds retardation in the mastery of new and difficult discrimination problems. However, Chow (1951) describes somewhat more extensive impairment; after lesions in the region of the middle temporal convolution his monkeys showed deficits in retention and in subsequent reacquisition of various visual discrimination habits.

The effects of damage to the ventromedial surface of the temporal lobes are more consistent and more striking. The most systematic behavioral study is that of Mishkin (1951), who reports that animals are as handicapped on formal tests of visual discrimination after ventral-surface extirpations as they are after complete removal of the temporal lobes, the only difference being that with the smaller lesions the visual disturbance is not apparent to casual inspection. Persistent impairment of form discrimination after damage to the "baso-medial" cortex of the temporal lobe is also reported by Poirier (1952), thus confirming the importance of this area for visual functions.

A further problem of localisation is raised by the suggestion that the peculiar effectiveness of deep temporal-lobe lesions may be due at least in part to destruction of the hippocampus (Kluver and Bucy, 1938; Lashley, 1948; Ades and Raab, 1949). The hypothesis has been refuted by recent work. Mishkin (1951) has data which indicate that where visual impairment follows removal of the hippocampus it is due to cutting of the white matter in the ventral surface of the temporal lobe, and not to destruction of the hippocampus per se. The fact that severing the fornix, and so interrupting the long projecting pathways of the hippocampus, has no effect on visually guided behaviour, strengthens this interpretation (Garcia-Bengochea, Corrigan, Morgane, Russell, and Heath, 1951).

The experimental evidence presented so far has established the special importance of the ventromedial part of the temporal lobe for visual discrimination; the lateral section is implicated to a lesser degree, and minimal disturbance follows damage to the prestriate cortex. But this account is incomplete, in that is is based on the effects of circumscribed lesions of temporal lobe or prestriate cortex. There is also evidence to show that posterior-cortex ablations which involve combined destruction of the prestriate and lateral-temporal neocortex are in fact exceedingly damaging to visual function.

Lashley and Clark (1946) point out that there is no anatomical justification for subdividing the posterior association area of the macaque neocortex into separate parietal, temporal, and preoccipital regions. It is also known that only minor behavioral changes result from isolated destruction of any of these areas (Ruch, Fulton, and German, 1938; Lashley, 1948; Ades and Raab, 1949). On the basis of such facts Blum, Chow, and Pribram (1950) argue that the posterior neocortex, exclusive of sensory projections, should be treated as a unit, and that, as such, it must be ablated in its entirety if we are to discover its true functional significance. They accordingly made extensive lesions on the lateral aspect of the posterior cortex, involving damage to parietal, temporal, and preoccipital regions, and thereby produced a very marked loss of discriminatory ability. It is remarkable that such lesions cause at least as much visual impairment as does complete removal of the temporal lobes, despite the fact that the important ventromedial area of the temporal lobe is left intact. This finding has since been amply confirmed (Riopelle, Harlow, Settlage, and Ades, 1951; Warren and Harlow, 1952); it is also consistent with an earlier report of permanent loss of a pattern-discrimination habit after combined destruction of the lateral-temporal and prestriate regions (Ades and Raab, 1949). It should be emphasised that these severe and persistent disturbances of discriminatory function do not automatically accompany any large cortical lesion, but are specific to bilateral posterior-cortex extirpations; only mild and essentially transient effects follow bilateral prefrontal, or extensive unilateral ablations (Riopelle, Harlow, Settlage and Ades, 1951; Warren and Harlow, 1952). It is interesting that very similar conclusions have recently been reached concerning complex visual functions in man (Teuber, Battersby, and Bender, 1951).

To recapitulate: it has been established that in the macaque visual learning ability depends on the integrity of a small area of extra-striate cortex, the ventromedial surface of the temporal lobe, while no small lesion elsewhere is crucial. Much larger destructions of lateral temporal surface and preoccipital cortex have equal or greater effect. It appears therefore that facilitation from the lateral-temporal prestriate complex is required for the functioning of the ventromedial focus, or, as an alternative statement, that the two form a single system in which the smaller ventromedial area has a special importance.

Somaesthetic Functions of the Temporal Lobe

While the ablation studies described above leave no doubt as to the importance of the temporal lobes for vision, the evidence is far less conclusive in the case of somaesthesis. It is true that Kluver and Bucy inferred from the behaviour of their animals that they were unable to recognise objects tactually after removal of the temporal lobes, and thus that their "psychic blindness" was not exclusively visual. There was however no loss of cutaneous sensivity, and unfortunately no complex tactual and kinaesthetic tests were given. At first sight the suggestion that temporal-lobe damage may interfere with somaesthetic functions is a little disconcerting, since the parietal lobe is the traditional locus of such functions, and the somaesthetic importance of the posterior parietal lobule has long been recognised (Ruch, Fulton, and German, 1938). Recently, however, Blum Chow, and Pribram (1950) and Blum (1951) have shown that extension of parietal lesions into the posterior cortex of the temporal lobe causes a greater somaesthetic impairment than do posterior parietal lesions alone; the loss was measured by means of an extensive test battery which included tactual latch-box and form-discrimination problems. These studies also show conclusively that in the monkey temporal-lobe ablation by itself is essentially without effect upon such tests; the most that could be demonstrated was a slight difficulty in the discrimination of roughness (Blum, Chow, and Pribram, 1950). It follows from these two findings that the temporal lobe is not focally concerned in tactual and kinaesthetic functions, but that it can play a minor role, at least when the more important parietal area is excised.

Blum has already commented on the similarity between these findings and those of Evans on tactual and kinaesthetic deficit in cases of human brain damage (Evans, 1935; Blum, 1951); both human and animal studies suggest that damage to cortex posterior and inferior to the acknowledged somaesthetic area of the posterior parietal lobule increases the sensory deficit. There is also evidence that greater and more enduring somaesthetic deficit results from cortical ablations in man than in chimpanzee, and in chimpanzee than in monkey (Ruch, Fulton, and German, 1938; Blum, 1951). These facts combine to suggest that some somaesthetic loss may be expected in man after removal of the temporal lobes, even without parietal injury.

THE PHYSIOLOGICAL PROBLEM

As has been seen, behavioral studies show beyond doubt that the temporal lobes mediate important visual functions; the question therefore arises as to the nature of the central nervous pathways involved. The first problem is to locate conduction pathways from the visual receiving area to the temporal lobes, which are able to survive extensive damage to areas 18 and 19. Data will be presented which argue strongly against an explanation in terms of transcortical systems alone, and which emphasise rather the role of the pulvinar in higher visual functions. A further problem is posed by the fact that similar visual deficit results from either small lesions on the ventral surface of the temporal lobes, or from much larger removals on the lateral surface of the posterior association cortex.

Strychnine neuronography has distinguished three zones within the temporal cortex of the macaque, and these differences appear to be correlated with differences in function. The three subdivisions are: the temporal pole; the supratemporal plane, together with the cortex on the superior lateral surface of the temporal lobe; and, lastly, the main temporal sector comprising the ventral and posterolateral portions of the temporal lobe. It is this third section only which has been implicated in visual functions, and its organisation is therefore of paramount interest here. What is known of the other two temporal regions may be briefly summarised. The temporal pole, an anatomically distinct region, has connections with many areas, notably the orbito-frontal cortex and the amygdala (Pribram, Lennox and Dunsmore, 1950; Lennox, Dunsmore, Epstein and Pribram, 1950). It is chiefly concerned in autonomic functions (Kaada, Pribram, and Epstein, 1949), though recent electrophysiological studies reveal diffuse connections between the temporal tip and the posterior association nuclei of the thalamus, suggesting that the polar region has more in common with the main temporal sector than is generally supposed (Ajmone-Marsan and Stoll, 1951). The second region, that of the supratemporal plane and adjacent cortex, contains the projection field of the medial geniculate, and subserves audition. Thorough studies have been made of its transcortical and intracortical connections (Bailey, Bonin, Garol, and McCulloch, 1943a; Sugar, French and Chusid, 1948).

The main temporal region has many connections with other cortical areas, the most suggestive from the standpoint of visual function being those to and from the prestriate cortex. Such connections have been found for both the posterior-lateral and the inferior temporal regions (Mettler, 1935; Bailey, Bonin, Garol, and McCulloch, 1943b; Petr, Kralove, Holden, and Jirout, 1949). In contrast to this it has generally been believed that there are few thalamic projections to this area (Walker, 1938), though Chow (1950) has now provided anatomical evidence for projections from the posterior part of nucleus pulvinaris medialis to the lateral surface of the temporal lobe, and has confirmed earlier reports of projections from the posterior part of nucleus pulvinaris lateralis to the posterior temporal cortex.

In trying to elucidate the role of this main temporal area in visual functions, we run at once into the following difficulty. It is known that the striate cortex (area 17) has no direct connections with the temporal lobes, but fires locally into area 18, which thus acts as a way-station for transcortical impulses from the primary receiving area (Bonin, Garol and McCulloch, 1942; Clark, 1942). Yet we have seen that extensive damage to areas 18 and 19 does not interfere greatly with visual learning; particularly striking is Evarts' (1952) demonstration that extensive ablation of area 18 has no effect on either retention or post-operative learning of a "conditional" problem requiring the association of visual and auditery cues. An attempt to explain such data purely in terms of transcortical connections must assume that the small ventromedial section of area 18 remaining can function equipotentially for the whole; this seems particularly unlikely when we consider that only short association fibres are found in the visual cortex (Clark, 1941), and that the region of area 17 immediately adjacent to the intact remnant of area 18 in Evarts' experiment represents the most peripheral part of the visual field (Marshall and Talbot, 1942). One must therefore look elsewhere for pathways to account for extra-striate visual functions.

It seems most likely that transmission via subcortical relay and association nuclei will provide the answer. In support of this, recent physiological studies of Jasper and his co-workers may be cited (Jasper, Ajmone-Marsan, and Stoll, 1952). Working with monkeys under local anaesthesia and sodium pentobarbital sedation, Jasper, Ajmone-Marsan, and Stoll found that local electrical stimulation of area 17 produced strong firing in a narrow zone of the lateral geniculate and simultaneous firing of the adjacent portion of nucleus pulvinaris lateralis. In fact their results suggest that after-discharge in area 17 is conducted more readily over subcortical pathways than transcortically to the parastriate area. As there are projections from nucleus pulvinaris lateralis to the posterior temporal region, it seems that we have here a means of by-passing the prestriate cortex. Arguing against this view, Chow (1952) points out that prestriate ablations may cause degeneration in the lateral part of the pulvinar without there being any lasting visual deficit. However, in the one case of this kind reported, the locus of cell degeneration in the pulvinar was not coextensive with the area to which the striate cortex fires, although admittedly there was some overlap. The evidence at present is not sufficient to settle the question finally one way or the other, but the apparent absence of adequate cortical connections in such cases is presumptive evidence for a subcortical relay of the type described. The fact that combined destruction of posterior-temporal and prestriate cortex causes permanent visual impairment supports this view, suggesting as it does that in such cases both the transcortical and the corticothalamic pathways from area 17 have been cut.

It remains to discuss briefly the second problem posed by behavioral studies: how destruction of a small area on the ventromedial surface of the temporal lobes, or interruption of some of the pathways serving it, causes deficits as severe as those seen with extensive damage to the lateral surface of the posterior association cortex. The behavioral evidence clearly shows that the ventromedial portion of the temporal lobe contains an important centre for visual elaboration. Physiological studies have revealed an area on the ventral surface to which impulses from the surrounding temporal cortex and from the prestriate area appear to converge, and which itself sends efferent impulses to the prestriate cortex (Petr, Kralove, Holden, and Jirout, 1949). Ventromedial-surface extirpations could therefore be expected to interrupt many cortical circuits; it is probable that such lesions also disrupt circuits between temporal lobe and pulvinar.

Blum, Chow, and Pribram (1950) and Chow (1952) have denied the importance of these subcortical connections, but the evidence does not entirely justify their position.

The principle evidence cited by Blum, Chow, and Pribram is that there is no correlation between visual deficit and either extent or locus of degeneration in the pulvinar. However, absence of retrograde degeneration in a thalamic nucleus is no final proof of lack of connections between that nucleus and the area of cortex destroyed. As Jasper, Ajmone-Marsan, and Stoll (1952) have pointed out, projecting thalamocortical fibres may have widely distributed collaterals which may protect the cells of origin from degeneration. This would explain the negative results of degeneration studies following medium-sized ablations in the posterior association cortex. It is known that hemidecortication causes complete degeneration in the pulvinar, while ablations of parietal or temporal cortex alone have only minor effects (Clark and Boggon, 1935; Clark and Northfield, 1937; Walker, 1938). A further point is that loss of function may also be caused by interruption of corticofugal connections from temporal lobe to pulvinar. Such corticofugal connections have been demonstrated by Jasper, Ajmone-Marsan, and Stoll in the study described above.

The main conclusions from this discussion can be summarised as follows. There is a focus for visual elaboration in the ventromedial section of the temporal lobe, and it is reasonable to believe that lesions in this area disrupt important corticocortical and thalamocortical circuits. It has been argued that the deficit seen with extensive lateral surface ablations is partly due to the severing of pathways from area 17 to the temporal lobes; but there is no inconsistency in supposing that the lateral-temporal and prestriate areas are themselves implicated to some extent in the synthesis of visual perceptions.

REVIEW OF HUMAN CLINICAL STUDIES

In contrast to our present extensive knowledge of the deficits caused by temporal-lobe damage in monkeys, we can still only speculate as to the effects of such lesions in man. This ignorance is due in part to the clinical preoccupation with the frontal lobes, in part to a lack of adequate psychological testing when the temporal-lobe case is seen, and perhaps most of all to the unsatisfactory nature of the clinical material. It is unfortunate that the few psychological studies reported deal with cases of brain tumour, where it is notoriously difficult to assess the full extent of brain damage, and where increased intracranial pressure may produce disturbance far from the site of the primary lesion. Even in cases of penetrating head-injury or of vascular accident, it is unlikely that damage will be neatly restricted to the temporal cortex, and, failing autopsy, we can have only an approximate idea of the area of brain destroyed. The fact that bilateral temporal-lobe lesions in man are rare presents another obstacle to our understanding of temporal-lobe function, although the manifest non-equivalence of the two hemispheres, at least for language, suggests that unilateral studies may be more rewarding at the human than at the animal level.

Despite the lack of precise information concerning temporal-lobe function in man, the gross symptomatology of temporal-lobe disease has long been known. The personality changes which are a conspicuous feature of human temporal-lobe pathology have already been mentioned. Sensory disturbances and complex visual hallucinations are equally striking symptoms, and gain in significance when we consider that visual impairment is the characteristic feature of temporal-lobe damage in monkeys. Finally, there is aphasia, which often accompanies lesions of the left temporal lobe, and which will require special discussion later.

Among the sensory disturbances seen in cases of temporal-lobe tumour, auditory anomalies such as tinnitus are the most common (Frazier and Rowe, 1934) presumably providing the most reliable localising sign. The occurrence of olfactory hallucinations is said to imply involvement of the uncus and adjoining rhinencephalic structures at the base of the temporal lobe. Homonymous visual field defects are another frequent symptom, and Cushing states that these are usually limited to the upper quadrant contralateral to the lesion and typically show no macular sparing; such defects are taken to indicate damage to the optic radiations as they course round the inferior part of the lateral ventricle into the white matter of the temporal lobe (Cushing, 1922). In agreement with this Penfield finds that cutting of the white matter below the cortex and five centimetres posterior to the temporal tip produces a homonymous hemianopsia; however in these cases there appears to be sparing of the contralateral half of macular vision (Penfield and Rasmussen, 1950).

As for the more complex visual disturbances, it has been known for some time that various phenomena such as déjà vu, micropsia and macropsia, and formed visual hallucinations, may be among the earliest signs of temporal-lobe disease (Hauptmann, 1931b; Frazier and Rowe, 1934), and indeed this finding led Hauptmann (1931b) to suggest that the temporal region might mediate important visual functions. Moreover, in epileptic patients paroxysmal discharge within the temporal lobe may give rise to perceptual illusions or hallucinations; such states have been called "dream states" by Hughlings Jackson and "psychical seizures" by Penfield. It is interesting that in such patients electrical stimulation of the exposed temporal cortex may produce complex hallucinations, both auditory and visual, and sometimes appears to reactivate old memories. However, such effects are not elicited by stimulation of the temporal cortex in patients whose epileptic foci are elsewhere (Penfield and Rasmussen, 1950).

It is largely on the basis of these stimulation studies that Penfield has come to attribute to the temporal lobes an unique role in the preservation of memory traces, but it would be strange if this did not turn out to be too simple a view. Certainly temporal-lobe removal in monkeys does not cause a general memory loss, but has a more specifically visual effect.

It is now time to consider what has been explicitly stated about intellectual functions in temporal-lobe disease. As was suggested earlier, the clinical literature of brain tumour deals mainly with mental disturbance gross enough to disrupt everyday behaviour. Summarising the findings in such cases, Klebanoff (1945) states that the presenting symptoms of intellectual deterioration are similar to, but on the whole less severe than, those seen in frontal-lobe tumour; thus the patient may appear confused, and may show memory disturbance and inability to concentrate. The fact that the onset of these non-specific intellectual defects may be delayed in temporal-lobe cases has led to the view that they may be secondary effects due to involvement of the frontal lobes; an interpretation which clearly reflects the traditional view that the frontal lobes are the site of man's intellectual functions. There is indeed a suggestion that in the temporal-lobe cases the memory loss is apt to be particularly severe, affecting both recent and remote events (Kolodny, 1928), but the fact that removal of the tumour by resection of the temporal lobe normally causes an abatement of the gross symptoms of mental impairment advises caution in drawing such a conclusion.

In two studies where systematic mental testing was done following excision of temporal-lobe tumours, the aim was to study the function of the frontal rather than the temporal lobes. Thus Rylander (1943) and Halstead (1947) include temporal-lobe cases in their brain-damaged control groups, and both writers affirm that lesions outside the frontal lobes cause no impairment comparable with that found in their frontal lobe cases. Yet the value of such assertions may be questioned. In the first place, Rylander deliberately excluded from his control group patients with damage to either the left-parietal of left-temporal lobes, on the grounds that in such cases surgical intervention might greatly injure "the tools for mental activity". This treatment of language as a mere tool is dubious enough, but the risks inherent in such a restricted choice of subjects are here heightened by the use of a test battery composed largely of verbal tests. If, as will be suggested later, the right temporal lobe contributes mainly to the non-verbal aspects of intelligence, then Rylander has not adequately explored the probable areas of intellectual deficit in his seven patients with right temporal-lobe lesions. In the second study, that of Halstead, nine temporal-lobe cases are reported, but in only four of these (two left-sided and two right) did the removals approach complete lobectomy. Of these, the two left-sided cases showed intellectual impairment at least equal to the average for the frontal-lobe group, while the right-sided cases gave negative results. This means that Halstead's special tests are in fact sensitive to left temporal-lobe destruction.

From this point onwards the effects of right and left temporal-lobe damage will be treated separately: firstly, because of the prevalence of language disturbances (aphasia) after lesions of the left temporal lobe; and secondly, because of the possibility, hitherto unproven, that right temporal-lobe lesions may be more apt than left to cause deficit on certain non-language tests.

Aphasia and the Left Temporal Lobe

Precise information concerning the location of a speech area within the temporal cortex comes from electrical stimulation of the exposed brain in epileptic patients. This technique has revealed an area in the posterior temporal lobe where stimulation may either arrest speech or cause the patient to become aphasic (Penfield and Rasmussen, 1950). The anterior limit of this region is approximately seven centimetres from the temporal tip, and excision of all cortex anterior to it can safely be made without causing more than a transient aphasia.

The literature of aphasia provides striking evidence that clean surgical destruction is less damaging than an active disease process. Thus Roberts (1951) points out that the speech area in the posterior temporal cortex can be partially destroyed during the excision of an epileptogenic focus without any permanent aphasia, provided, that is, that the patient's seizures are stopped. Similarly, Fox and German (1935) and Neilson and Raney (1939) comment with surprise on the comparative mildness of the residual aphasia seen following complete resection of the left temporal-lobe in cases of cerebral tumour, a finding which apparently contrasts sharply with the crippling effect upon language of even minor vascular lesions within the same area (Neilson and Raney, 1939). The data are interpreted by these various authors as showing that the presence of partial damage within a speech area causes greater language disturbance than does the surgical removal of a much larger area. This is a special instance of a principle which has application beyond the field of language disorders: namely, that greater deterioration may result from the presence of abnormally functioning tissue than from mere absence of tissue (Jefferson, 1937; Hebb, 1939a; Blum, 1948).

If we now ask what the special characteristics of temporal-lobe aphasia are, we get no one clear-cut answer. Roberts (1951) carried out a detailed study of 71 cases of aphasia (following excision of cortex adjoining speech areas in frontal, parietal, and temporal regions), and found no relationship between either the severity or the duration of the language disturbance and the site of the lesion. This conclusion provides support for those who, like Goldstein, have been consistently opposed to the doctrine that different language functions are differently localised in the left cerebral cortex. However a more traditional view is that the aphasia seen in posterior lesions is primarily "receptive", (a disturbance of comprehension), as contrasted with the predominantly "expressive" disturbance seen with anterior lesions; Weisenburg and McBride (1935) explicitly accept this formulation, although they are careful to point out that there is always some expressive defect, making the difference one of degree only. Head (1926), who lays little stress on receptive disturbances, attributes his syntactic aphasia to lesions of the temporal lobe: a more popular view associates the temporal region with the auditory components of speech, with difficulty both in understanding and in retention of spoken language (Fox and German, 1935; Kennedy and Wolf, 1936; Obrador, 1947; Green, Duisburg and McGrath, 1951). These studies as a whole permit the conclusion that in temporal-lobe aphasia speech comprehension is rather obviously impaired, but not in isolation from other aspects of language.

We come now to the important question of how far aphasia (and here I include temporal-lobe aphasia) can be regarded as a purely linguistic disturbance which leaves "intelligence" essentially unimpaired, and how far it implies a more general intellectual loss. There are three main schools of thought: according to one, aphasia is merely a manifestation of a more fundamental intellectual disorder (Goldstein, 1926, 1948; van Woerkom, 1923; Bouman and Grunbaum, 1925; Wolpert, 1930); according to another, there may be loss, which does not affect all aspects of intelligence equally, so that the patient will do very poorly on some tests and comparatively well on others (Weisenburg and McBride, 1935; Fox and German, 1935; Hebb, 1942a); or again, there is the third possibility that aphasia is a mere loss of symbols, by which it is implied that the aphasic patient will have difficulties of communication, but no intrinsic difficulty in problem-solving (Isserlin, von Kuenburg, and Hofbauer, 1927; Lotmar, 1933; Hauptmann, 1931a; Kennedy and Wolf, 1936). Those who adopt this last position state that large cortical lesions *also* impair intelligence and that for this very reason such cases are not suitable for studying the typical patterning of abilities in aphasia (Hauptmann, 1931a; Kennedy and Wolf, 1936). It will be argued here that it is the second viewpoint for which there is the most empirical support.

It is clear that the testing-ground of these rival theories must be the domain of non-verbal skills. Here Kennedy and Wolf make the important point that many tests purporting to be non-verbal are in fact not so, since the score depends upon how well the patient has understood the verbal instructions; hence, unless it can be shown in a given instance that the patient has grasped what is required, the work is invalid. This means, in effect, that the only unequivocal results will be those cases in which the patient succeeds on the easy items of a test (showing that he has in fact grasped the instructions), only to fail later on more difficult ones (Hebb, 1942a). Unfortunately, not all tests used in studies of aphasia meet this criterion.

If the results in the clinical literature are taken at their face value, there is still ample proof that aphasia is compatible with normal performance on some non-verbal tests. Myers (1948) finds that aphasic patients perform as well as their matched normal controls on non-verbal tests of inductive reasoning of the multiple-choice kind. Similarly, von Kuenburg (1930) has failed to find clear-cut differences between aphasics and normal control subjects on sorting tests calling for various classifications of colours and objects. Such studies are valuable in underlining the difficulty that many normal persons have on such tasks, a fact which is too often ignored in clinical studies.

Nevertheless it would be idle to deny that aphasic patients often show impairment on non-verbal tests. Van Woerkom demonstrated such deficits in individual cases many years ago, and later work has essentially confirmed this finding. As was suggested earlier, the aim here is to show that the deficit is characteristically mild. Weisenburg and McBride report that their aphasic patients consistently made better scores on non-verbal tests and on arithmetic than on verbal tests, but that these scores were still distinctly lower than would have been predicted in the case of a normal person with the same educational history. A similar picture emerges from Hebb's study of six cases of aphasia following surgical excisions in the dominant hemisphere, and here repeated testing showed that the recovery of verbal and non-verbal functions followed the same time course (Hebb, 1942a). Finally, in a report of special interest for this present study, Fox and German (1935) present follow-up observations in a case of left temporal lobectomy for cerebral tumour: they report "average" performance on a series of non-verbal tests at a time when the patient continued to do poorly on verbal and mathematical tests; at this time (fifteen months after operation), the patient still became confused if he listened to speech for any length of time, although the more overt signs of aphasia had disappeared. These results are not inconsistent with the view that there had been some loss of non-verbal ability, since Fox and German consider that their patient was originally above average in intelligence, and thus assume that there had been some loss even in non-language fields. It is of course evident that a major difficulty in the way of an accurate appraisal of all such data is the lack of any objective measure of the patients' intellectual status before the onset of aphasia.

It seems that the above studies, incomplete as they are, justify the view that in aphasia the pattern of test performance is likely to be one of severe deficit on verbal tests and relatively mild deficit on non-verbal ones. There is the further point that the degree of this disparity between verbal and non-verbal scores varies markedly from person to person, and with the tests used. These differences, which are very striking, are almost certainly related to the site of the lesion, but how, and to what extent, the data do not permit us to judge. An additional factor may be the degree to which the individual normally relies on verbal cues.

The studies outlined above show the typical patterning of test performance in cases of diffuse pathological damage to the left hemisphere, often involving the temporal cortex. It is reasonable to suppose that a clean surgical removal of the left temporal lobe (without brain tumour), would also affect verbal more than non-verbal performance, but that the over-all deficit would be less severe.

Special Functions of the Right Hemisphere

The absence of aphasia following lesions in the right hemisphere has led to a neglect of possible intellectual loss in such cases, and has probably encouraged the view that the right cerebral cortex plays an essentially ancillary role in intellectual functioning. It will be shown, on the contrary, that the evidence suggests that damage to the posterior association cortex on the right produces deficit different in kind from that caused by comparable damage on the left, rather than an attenuated form of the same disturbance. The data relating specifically to the right temporal lobe are unfortunately extremely meagre, but they are completely consistent with the view just outlined. However, as in the case of aphasia, most of the clinical evidence comes from diffuse pathological processes.

The first suggestion that right hemisphere damage might cause its own characteristic deficit comes from Weisenburg and McBride's detailed psychometric study of 22 cases of right-sided lesion without aphasia. Although these patients were slightly inferior to matched normal controls in occupational and educational level, this fact cannot account for the irregular nature of the test profiles obtained. Thus, while they approach the normals most closely on some verbal tests, they are significantly inferior on the arithmetic and most of the non-language tests, notably the Porteus Maze Test. The authors conclude that the performance-test battery revealed a significant deficit in the appreciation and manipulation of forms and spatial relationships. These results are quite different from those obtained by the same workers with their aphasic group; the latter, it will be recalled, approached the normal most closely in non-language work and arithmetic. We have no precise knowledge as to the extent of brain damage in the two groups, but Weisenburg and McBride explicitly state that they were ideally matched in this respect. However, it is not clear from the way the data are presented that the absolute mean scores of the right-hemisphere group on non-language tests were lower than those of the aphasic group. If they were not, then we cannot conclude that the right hemisphere is more important than the left for the non-language tests of Weisenburg and McBride's battery. All that has been shown is that these tests are more sensitive than verbal ones to right-hemisphere damage.

Further evidence on this point is provided by Hebb (1939a), in the case of a patient who had had a complete right temporal lobectomy for the removal of epileptogenic scar tissue. This patient performed well on all verbal tests, with Stanford-Binet Vocabulary at Superior-Adult level and full-scale I. Q. of 113, but revealed a startling deficit on tests of form perception, both visual and tactual; a finding which is in marked agreement with the results of Weisenburg and McBride. Hebb also reports that his patient had difficulty in following conversations involving more than two or three people, so that he would often make inappropriate remarks. This is an interesting observation, suggesting as it does a type of impairment which neither a conventional test battery nor a clinical interview could be expected to reveal. The study is particularly relevant to the present investigation in that it deals with the effects of a well-localised lesion of one temporal lobe (although it should be added that there had also been a very small cortical excision in the pre-central gyrus). Moreover, as the tests were carried out eight years after the temporal lobectomy, it seems safe to assume that the deficits observed were permanent. This study is unfortunately incomplete, in that there are no pre-operative data. Yet it is worth noting that McFie, Piercy and Zangwill (1950) have described a similar picture of superior verbal intelligence combined with marked loss of "visuo-constructive ability", in the case of a 36-year old engineer with a glioma of the right temporal lobe. In this instance the patient's profession seems reason enough for regarding the deficit as a direct result of the temporal-lobe tumour.

This exhausts the evidence relating visuo-spatial abilities specifically to the right temporal lobe. There remain a number of studies stressing the importance of the right hemisphere, and more particularly of the right pareto-occipital cortex, for effective spatial organisation. The symptoms said to be more common in right than in left hemisphere lesions include: disturbance of the coordinates of visual space (Lenz, 1944; Bender and Jung, 1948, cited by McFie, Piercy and Zangwill, 1950; Hécaen, Ajuriaguerra and Massonnet, 1951); poor performance on visuo-constructive tasks such as map-drawing and block design (Dide, 1938; McFie, Piercy and Zangwill, 1950; Hécaen, Ajuriaguerra and Massonnet, 1951); difficulty in putting on one's clothes, "apraxia for dressing" (Dide, 1938; Hécaen and Ajuriaguerra, 1942-45). Such findings are of course not in accordance with the traditional view, which states that damage to the right parieto-occipital cortex merely causes neglect of the left side of the body and of the left half of the visual field (Brain, 1941; Critchley, 1951). Further, many of the cases on which the above reports are based involve massive, infiltrating tumours, so that bilateral damage can often be suspected. Yet this objection does not dispose of all cases; the growing number of such reports, together with the diversity of their sources, support the idea that there is in fact a significantly higher incidence of visuo-constructive disorders in right-hemisphere lesions than in left. Whether or not the right temporal lobe is involved in these disorders remains to be seen. In the temporal-lobe case described above, McFie, Zangwill and Piercy appear to interpret their positive findings as implying concomitant damage to the parietal lobe. This being so, only Hebb has specifically implicated the right temporal lobe in visuo-spatial deficit.

If the temporal-lobe literature is considered as a whole, it is immediately apparent that the human and the animal work have developed along very different lines. The lack of any data on visual discriminatory capacity in human temporal-lobe damage is a conspicuous gap in our knowledge, a gap which is all the more remarkable in view of the known prevalence of visual disturbances in temporal-lobe disease. The animal work has provided valuable information in this regard; the only human study at all comparable being that of Teuber, Battersby and Bender (1951) which shows that posterior gunshot wounds cause greater detriment on complex visual tasks than do anterior ones, but their findings are not directly pertinent to temporal-lobe function.

THE PRESENT INVESTIGATION

The present investigation attempts to carry further the study of temporal-lobe function, in conditions especially advantageous for observing the effects of well-localised lesions in the human temporal cortex. An opportunity was provided at the Montreal Neurological Institute to study the intellectual abilities of patients, from Dr. Wilder Penfield's service, who had been selected for surgical therapy for the relief of focal cerebral seizures. In most cases the epileptogenic area was located in one or other temporal lobe, so that it was possible to see the effects of destruction of temporal-lobe tissue without the confusing presence of brain tumour or vascular disease. To ascertain how far any deficits found were specific to lesions of the temporal cortex, comparable cases of frontal- and parietal-lobe damage were included in the study and were treated as a control group for the purposes of the present investigation.

In view of the outcome of recent animal studies, the main emphasis in this study was given to visual functions. A special search was also made for any consistent differences between the effects of right and left temporal-lobe lesions. The clarification of the language deficit seen transiently after left temporal-lobe ablation was not one of the aims of the investigation, although some of the data obtained did prove pertinent to this question.

THE SUBJECTS STUDIED

Of the 45 subjects studied, 38 had cortical epilepsy, attributable to well-localised atrophic lesions, usually dating from birth or early infancy. In four cases there was local scarring of the brain due to adult head injury. All were operated on by Dr. Penfield, who in most cases reproduced the patient's aura by electrical stimulation of the cortex under local anaesthesia; the epileptogenic area was then excised.

The experimental group consisted of 25 patients with temporal-lobe foci (13 right-sided, 12 left). Five of these patients had previously had small excisions in the temporal cortex, two on the right and three on the left, and returned now for a second operation in the same general area; the results for these five patients are not included in the statistical analysis of pre-operative test performance, but it is worth noting that they are completely consistent with those obtained from the group of patients being operated on for the first time.

Three of the temporal-lobe patients were left-handed. In all three cases, however, the left hemisphere was clearly dominant for language. Thus, in the two cases in which the operation was on the left side, stimulation of the exposed cortex disturbed speech, and the patient became aphasic after operation; in the case of the one left-handed patient with an epileptogenic focus in the right temporal lobe, electrical stimulation of the cortex did not affect speech, and no language disturbance could be discovered after operation. There is of course much empirical evidence to show that the right hemisphere is rarely dominant for language, even in left-handed persons, except in cases where there is also right hemiplegia due to gross destruction of the left hemisphere dating from the first two years of life (Wepman, 1951; Roberts, 1951).

The extent of temporal-lobe removal was estimated from measurements and drawings made by Dr. Penfield at the time of operation. Figures 1 and 2 show the largest removals made in the right and left temporal lobes, respectively. In the experimental group as a whole, the dimensions of the excised areas as measured back from the temporal tip vary from 4 to 8 centimetres along the base, and from 5 to 8 centimetres along the lower bank of the fissure of Sylvius. It is important to note that the abnormality was usually found on the ventral and mesial surfaces of the temporal lobe and that the removal of tissue often extended to include the uncus, amygdaloid nucleus, and hippocampus. In only three patients was the removal restricted to the lateral aspect of the temporal lobe. In about half the cases there was surgical interruption of the optic radiations which resulted in a homonymous defect in the upper quadrant of the visual field, on the side contralateral to the lesion.

In addition to the 25 temporal-lobe cases, 13 patients with epileptogenic foci in frontal or parietal cortex were also tested, before and after brain operation. These control operations consisted of 6 left-frontal, 3 right-frontal, and 4 right-parietal excisions. The size of the removals varied considerably. Of those in the parietal lobe, two included most of the posterior parietal lobule as well as the postcentral gyrus; the other two were similar, but did not extend quite as far posteriorly. Among the frontal-lobe cases, 2 showed maximal abnormality in the anterior frontal region, and at operation the first 5 or 6 centimetres of the frontal lobe were amputated. The remaining ablations were mainly in the superior mid-frontal region, extending forward by varying amounts. Care was taken not to invade Broca's area in any of the left frontal removals. Included in the frontal group are two cases of bilateral frontal-lobe damage, but the excision was on the side of greater abnormality only. Considering the frontal and parietal cases as a whole, we see that some of the removals were comparable in size to the temporal-lobe ones, others being clearly smaller. However it is noteworthy that the test battery did not show any relationship between size of ablation in frontal or parietal cortex and degree of impairment.

This study was not planned to include a normal control group, its purpose being to investigate the special effects of temporal-lobe lesions as compared with lesions elsewhere, and differences in the effect of right and left temporal-lobe lesions. But some of the tests used were unstandardised, and the procedure in others was modified, so it was worthwhile to have some normal control data. Seven convalescent patients at Queen Mary Veterans' Hospital, Montreal, were given the test battery. They were selected to match the brain-damaged groups as far as possible in age, vocabulary, and occupational status, and they did not suffer from any neurological, psychiatric, or glandular disability. It is of interest to note that this small normal control group, inadequate as to number of cases included, resembled the frontal and parietal lobe cases very closely on almost all tests.

The essential control groups of this study are: first, the parietal and frontal cases, showing that it is nor mere presence of epileptogenic tissue, but its locus, which determines the deficits seen with temporal-lobe damage; and secondly, the left temporal-lobe patients, showing that the right temporal group had deficits that the left did not. Tables 1 and 2 give evidence of the comparability of these various groups, apart from the presence or absence, or locus, of cerebral lesion. Throughout this study the score on the Stanford-Binet Vocabulary Test (1916 edition) is taken as an index of the patient's intellectual level before operation, providing a further check on the comparability of the several groups. It should be noted that the mean score for all subjects was 28, slightly above the mean for normal adults cited by Weisenburg, Roe, and McBride (1936).

EXPERIMENTAL PROCEDURE

The battery of tests was given to each patient individually before and after operation. The first test sessions took place from 12 hours to five days before operation, and the re-testing about three weeks later, at the time of the patient's discharge from hospital. The precise time of retest depended on the rate of recovery of the individual patient, but it was always between the sixteenth and twenty-second post-operative days. Testing was divided into two sessions of about one and one-quarter hours each, both before and after operation, making a total of four sessions in all. The conditions of testing (such as place and time of

TABLE 1

Group Comparisons with respect to Age, Sex, and Vocabulary

Group	N	Age	Sex		Stanford-Binet Vocabulary (Form I)	
		Mean and Range	M	F	Mean	Standard error
Right temporal	11	29 (17-47)	6	5	27.9	± 1.56
Left temporal	9	27 (16-43)	5	4	29.4	± 2.38
Frontal and Parietal	13	26 (14-41)	11	2	28.8	± 1.45
Normal	7	28 (19-38)	6	1	28.3	± 2.14
Additional cases (2nd operation)						
Right temporal	2	31 (27-35)	2	-	30	± .71
Left temporal	3	32 (24-45)	2	1	28.3	± 1.35

TABLE 2

Distribution of Occupations in the Various Groups

Occupation	Main Groups				Additional Cases (2nd operation)	
	Right Temporal	Left Temporal	Frontal and Parietal	Normal	Right Temporal	Left Temporal
Professional	1	1	1	1	1	1
Business executives	1	1	1	1	-	-
Students						
University	1	-	1	-	1	1
College	2	1	2	-	-	-
Office workers	2	2	3	2	-	-
Skilled labourers	-	1	2	1	-	-
Unskilled labourers	1	1	1	1	-	-
Housewives	2	1	1	1	-	1
Unemployed	1	1	1	-	-	-

day) were kept as far as possible the same before and after operation for any given patient, and the order in which the tests were presented was constant for all subjects. Where two tests appeared to measure similar functions, as with the two tests of block design, they were given in different sittings. Also, it was thought advisable to intermingle verbal, pictorial, and spatial tests, in order to retain the subject's interest, and prevent discouragement after a series of failures, since some of the tests appeared easier, or more interesting, to the patients than others. Wherever possible, different forms of the same test were used before and after operation, so as to minimise the effects of practice; however, in such cases any striking drop in score after operation was always checked by having the patient take the first form of the test again.

Many tests were tried before the final battery was selected. In general it was considered desirable to have tests that were short, acceptable to the adult patient, and not such as to entail the use of cumbrous equipment; this last point was particularly important, since testing had sometimes to be done at the patient's bedside. The tests finally selected are listed below:

1. The Stanford-Binet Vocabulary Test (1916).
2. The Wechsler Similarities subtest.
3. The Fourth Word Series (analogies test: Hebb, 1942b).
4. The McGill Verbal Situation (Hebb and Morton, 1943).
5. The McGill Picture Anomaly Series (Hebb and Morton, 1943).
6. The Wechsler Picture Arrangement subtest.

7. The Wechsler Picture Completion subtest.

8. The Raven Progressive Matrices (1938 edition), Sets A, B, and C.

9. The (pictorial) Analogies subtest of the California Test of Mental Maturity (C.M.M.): Elementary and Intermediate Series (1946 edition).

10. The Benton Visual Retention Test (Benton, 1945).

11. The Wechsler Block Design subtest.

12. The Triangular Blocks Test (an experimental block-design test, unpublished).

13. The Halstead Tactile Formboard.

14. The Porteus Maze Test: Vineland Revision (1919).

15. The Wechsler Digit Span subtest.

16. The Wechsler Digit Symbol subtest.

It should be pointed out that certain modifications of standard procedure were introduced for several of the tests. The Progressive Matrices and the C.M.M. Analogies tests were given individually, which makes the published norms inapplicable to this study. Also, in the Progressive Matrices test the first three sets of problems were divided into two series (A2, 3, 6, 7...and A1, 4, 5, 8, 9...) for use before and after operation. It should also be noted that the McGill Picture Anomaly Series included 34 items in each series, instead of the 30 reported in the standardisation of the test. Lastly, for the Tactile Formboard Test, Halstead's (1947) procedure was modified slightly in that the subject was required to place the ten differently shaped blocks in the appropriate holes twice only, and was allowed to use both hands. In this case the changes were introduced to reduce testing time, and so make an apparently rather disturbing test more acceptable.

In this battery, tests were included which appear to measure the same or similar functions in a normal population, but which differed in mode of presentation. After brain injury, a test may become an index of something it is not meant for — a crude example being the effect of loss of visual acuity on a performance test, whereas a non-visual performance test may show that the loss is sensory rather than intellectual. In the present test battery, the C.M.M. Analogies subtest and the McGill Fourth Word Series both measure ability to reason by analogy, but they differ in that one is visual (pictorial), and the other verbal. Again, both the McGill Picture Anomaly Series and the McGill Verbal Situation were designed to measure awareness of the way human beings in the North American culture usually behave in social situations; but here also the tests differ in that one is visual and the other verbal. Lastly, both the Halstead Tactile Formboard and the two tests of block design demand the appreciation of geometrical forms and spatial relationships, but in one case the problem is visual, in the other tactual. In all these instances a specifically visual deficit would affect the visual forms of the tests only.

It should be added that this battery did not include tests of simple visual and somaesthetic functions, because these are part of the regular neurological examination given to patients before and after operation. Also, thorough clinical testing for aphasia was carried out before and after operation by Dr. Lamar Roberts and Mr. Robert Sparks.

RESULTS

The most striking finding in this study was that the group with temporal-lobe lesions showed certain specific deficits before operation, and that the operative procedure at most intensified an already existing loss of function. An exception to this last statement is of course the transient aphasia which followed left temporal and left frontal removals; however, this did not develop until at least 24 hours after operation, and it is attributable to reversible pathological changes, which interfere with the functioning of tissue in the neighbourhood of the excision (Roberts, 1951; Forgays, 1952). In general, the results show that the presence of areas of long standing abnormality within the temporal cortex produces certain characteristic deficits. To anticipate the detailed account of the results, it may be said that the temporal-lobe group as a whole showed a specifically visual impairment. In addition to this, the right temporal group was inferior to the left temporal group, and to the other subjects, on certain tactual and visual tasks requiring the perception of spatial patterning.

Before giving the results, it should be explained that a simple analysis of variance was done for each test, wherever there was any suggestion of a significant difference between the mean scores for any two groups of subjects. If this analysis yielded an over-all F ratio significant below the 5 per cent level, Fisher's t technique was then used to test the significance of the difference between any two group means. If the F ratio was not significant, no further statistical analysis was made.

Temporal-lobe Cases versus Others

The first findings to be presented are based on a comparison of the test scores of the temporal-lobe cases as a whole with those of all other subjects. The three tests which differentiated between the right and left temporal-lobe groups (the Halstead Tactile Formboard and the two tests of block design) will be considered separately in the next section. Table 3 shows the mean raw scores on the other thirteen tests for the different groups before operation. It will be seen that there are a number of indications of mild loss in the brain-damaged groups compared with the normal group, but none of these is significant. Taken together, they may indicate an effect of the brain injury or, more probably in view of the literature, an effect of phenobarbital sedation.

A comparison of the scores of the temporal-lobe group with those of the frontal and parietal control group show the temporal-lobe group to be inferior on two visual tests. These are the McGill Picture Anomaly Series ($\underline{t} = 3.26$), and the Wechsler Picture Arrangement subtest ($\underline{t} = 2.80$). Both differences are significant below the 1 per cent level. The Picture Arrangement subtest (Wechsler, 1944) requires the subject to place a series of cartoon drawings in the right order to tell a story (as in a comic strip). In the Picture Anomaly Series, the subject is confronted with a number of crudely drawn scenes and has to point to what is most incongruous in each (for example: a man knocking his ci-

TABLE 3

Group Mean Scores before Operation (omitting Halstead Formboard and Block Design Tests)

Test	Group Temporal N = 20	Frontal and Parietal N = 13	Normal N = 7
McGill Picture Anomaly	24.9	28.7	28.7
Wechsler Picture Arrangement	8.75	11.1	11.0
Wechsler Picture Completion	10.4	10.4	11.5
Raven Progressive Matrices	13.1	13.3	14.4
Benton Visual Retention	5.5	5.3	6.1
C.M.M. Picture Analogies	21.4	22.2	23.0
McGill Fourth Word	22.2	23.5	23.0
Stanford-Binet Vocabulary	28.6	28.8	28.3
McGill Verbal Situation	11.7	11.5	11.5
Wechsler Similarities	10.6	10.4	10.8
Porteus Maze	13.6	14.4	14.5
Wechsler Digit Symbol	9.3	9.5	11.0
Wechsler Digit Span	9.5	8.9	10.8

garette ash into a woman's cup in a restaurant, or a broom being used to paddle a canoe). On this test, the frontal and parietal control group, as well as the normal subjects, responded quickly and accurately, while some of the temporal-lobe patients were slow and hesitant even when they gave the correct answer. (The score on the test is the number of correct responses, and speed of response is not taken into account.) Thus the inferiority of the temporal lobe group was actually even greater than the difference in scores would suggest.

After operation, the difference between the groups on these two tests was maintained, but not significantly increased. Both the temporal-lobe and the frontal- and parietal-lobe patients tended to make slightly lower scores on the Picture Anomaly Series after operation, and three temporal-lobe patients showed a marked loss. On the other hand there were other patients who improved. Form II of the Wechsler Picture Arrangement subtest is known to be a little easier than Form I (Gerboth, 1950), so that the lack of improvement on Form II, as compared with Form I, may actually imply a slight loss after operation, not specific to any group of patients. Against this, it may be pointed out that retest with Form I never confirmed any suspected deficits. Finally, neither before nor after operation did the other visual tests discriminate between the various groups.

Special Deficits of the Right Temporal-lobe Group

Clear evidence was obtained that lesions of the right temporal lobe impair the appreciation of spatial relationships. Some subjects in the right temporal group were severely handicapped on the tactile formboard and the two block-design tests, and the group as a whole made lower scores than other subjects on these tests. Tables 4 and 5 summarise the findings, but these require further clarification. While it is necessary to analyse the results for these three tests separately, it should be remembered that it is the combined deficit which is particularly significant.

An analysis of the results obtained with the Halstead Tactile Formboard shows the right temporal-lobe group to be markedly impaired, both before and after operation. This test makes use of the Seguin formboard, but the subject is blindfolded. Three scores are obtained: the average time in minutes for two trials (T); the number of shapes correctly recalled (S); and the number correctly localised (L). Before operation, the right temporal patients made poorer scores, on all three counts, than did the left frontal, left temporal, and right parietal patients. The differences between the scores of the right and left temporal-lobe groups for both time and number of shapes recalled were significant beyond the 1 per cent level. Analysis of variance failed to show group differences for localisation scores before operation. An interesting point was that two of the three patients with damage to the right frontal lobe also made poor time scores on this test, but the smallness of the sample prevents any generalisation with regard to right frontal-lobe function.

After operation, the right temporal-lobe group continued to do poorly, and both the S and L scores were significantly lower than those of

TABLE 4

Group Mean Scores for the Halstead Tactile Formboard

before and after Operation

Group	N	Mean time for 2 trials (minutes)		No. of shapes correctly re-called		No. of shapes correctly lo-calised	
		Before	After	Before	After	Before	After
Right temporal	11	6.0	4.5	4.6	4.8	2.0	1.8
Left temporal	9	3.2	3.3	6.6	7.1	2.6	2.9
Left frontal	6	2.8	3.0	5.6	6.5	3.7	4.0
Right frontal	3	7.3	4.6	6.0	7.1	2.8	2.5
Right parietal	4	3.8	6.3	5.8	6.5	4	4
		First test	Second test	First test	Second test	First test	Second test
Normal	7	3.4	2.8	6.6	7.0	4.1	5.6

TABLE 5

Group Mean Scores before and after Operation for

Visual Tests of Block Design

Group	N	Test: Triangular Blocks Before	Test: Triangular Blocks After	Test: Wechsler Block Design Before	Test: Wechsler Block Design After
Right temporal	11	9.4	7.8	9.5	9.0
Left temporal	9	10.1	11.4	11.5	12.1
Frontal and Parietal	13	10.7	10.6	11.8	10.2
		First test	Second test	First test	Second test
Normal	7	11.0	11.9	12.0	12.0

other groups (see Table 4 for details). However the picture had changed a little with regard to time scores, as the parietal group were now much slower than all other subjects. It is most likely that the slowing-down of the parietal-lobe patients was related to the loss of tactual sensitivity found in their neurological examination after operation. It must be emphasised that there was no corresponding disturbance of recall; the subjects in this group were able to profit from the long time spent placing the blocks in the board, and drew comparatively accurate reproductions showing the arrangement of the various shapes, That there was no general disturbance of form perception in these parietal-lobe cases is also shown by their good performance on visual tests of block design. Further, it was possible to retest one patient twelve months after an extensive parietal-lobe excision, and at that time his performance was better than before operation. This was not the case with two right temporal-lobe patients seen for follow-up study.

The important point appears to be the combination of poor time and poor recall scores in the right temporal group. Such a combination shows that despite being exposed to the board for a longer period than most other subjects, these patients were able to recall less. The main reason for the delay in placing the blocks appeared to be due to a difficulty in recognising the correct hole when they came to it; they had no difficulty in recognising the shapes of the blocks. The normal subject may waste time trying to place a block in the wrong hole, but seem to recognise the right hole instantly.

When we turn to the two visual block-design tests, we again find statistically significant evidence of the inferiority of the right temporal-lobe group. This does not apply to all the individuals of the group, and there is considerable overlap between the scores for the right temporal group and the other groups studied. However, none of the right temporal patients did as well as the best subjects in other groups. A further point to be stressed in considering the differences between the effects of left and right temporal-lobe lesions is that the left temporal-lobe patients consistently made higher scores on these tests than the frontal and parietal controls, and alone equalled the performance of the normal group. The individual differences in the frontal and parietal group on these tests were striking.

We shall consider the Triangular Blocks Test first, as this test was particularly interesting in showing a significant post-operative drop in mean score for the right temporal group. The Triangular Blocks test consists of a series of outline drawings which the subject has to copy, using two, three, or four black wooden blocks; these are of equal size, and cut in the form of right-angled triangles. Considerable data have been collected on this test at McGill University, but the standardization is incomplete. In the present study, the right temporal-lobe patients made slightly, but not significantly, lower scores than other subjects before operation. After operation, the mean raw score for the right temporal group dropped 1.8 points, as contrasted with a mean rise of 1.3 points for the left temporal group, a difference giving a P value of .001. The same test items were used before and after operation, so that the improvement of the left temporal group appears to be a normal practice effect.

In the case of the Wechsler Block-Design subtest, the results were different in that there was no significant difference between the scores before and after operation. Table 5 shows that the mean score for the right temporal group was lower than that for the left before and after operation, but in both instances the $\underline{F}$ ratio was slightly above the 5 per cent level. If we take the average of the individual scores before and after operation, the "within groups" variance is reduced, resulting in an $\underline{F}$ ratio significant at the 1 per cent level. The $\underline{t}$ value of 3.1 indicates that the right temporal-lobe group is inferior to the left at the 1 per cent level.

These formal measurements of spatial ability were supplemented by a few qualitatively evaluated tests, such as that of requiring the patient to draw a street map showing where he lived, or a plan of the hospital ward. Some of the patients with damage to the right temporal lobe were quite at a loss with such tasks, two of them being unable to represent the intersection of streets on a map. Similarly, drawings of animals and of common objects showed gross structural defects. Such severe disabilities were not found in any of the other groups.

The complex disturbance of spatial ability revealed by poor performance on the various tests considered in this section was not manifested by all the patients in the right temporal-lobe group. It was noticeable that the most severe disturbance occurred in cases where the removals extended far back along the inferior surface of the temporal lobe. A comparison of the excisions shown in Figures 3 and 4 illustrates this point. The case shown in Figure 3 had no impairment of visual or tactual form perception, either before or after operation; the one in Figure 4, in which the excision extended a shorter distance along the first temporal convolution, but farther along the base, showed severe impairment, and the deficit increased slightly after operation. The more extensive lesions in the right temporal lobe, as in Figure 1, caused extreme deficit.

Test Performance after Left Temporal-lobe Ablations

After operation, both the left temporal- and the left frontal-lobe patients showed a significant drop in score on all verbal tests, although clinical tests of aphasia sometimes showed little deficit at this time; no verbal impairment was found after excisions in the right hemisphere. An interesting finding was that the left-temporal group did worse than the left-frontal group on the McGill Verbal Situation ($t = 2.17$; $P = .05$), whereas the Fourth Word and Wechsler Similarities tests did not differentiate between these groups. The Verbal Situation Test calls for ready comprehension of short extracts of conversation, and the left temporal-lobe patients often missed the point of the questions. This supports the view that, in temporal-lobe aphasia, auditory comprehension is particularly affected.

It has already been pointed out that the left temporal-lobe patients were competent on block-design tests, before and after operation. An unexpected finding was their excellent performance on the Porteus Maze Test after operation. Before operation there was no difference between

Figures 1 to 4. Brain maps (lateral and ventral views), showing representative temporal-lobe removals, as estimated by Dr. Penfield at the time of operation.

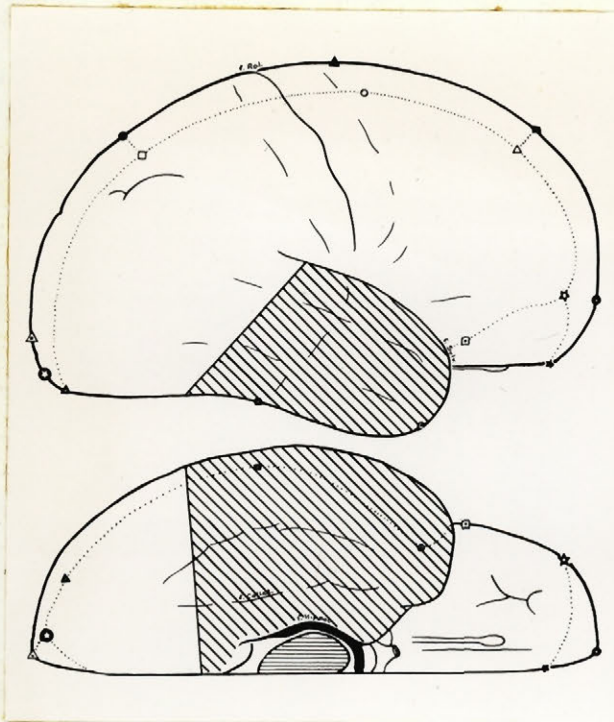

Fig. 1 Large right temporal removal.

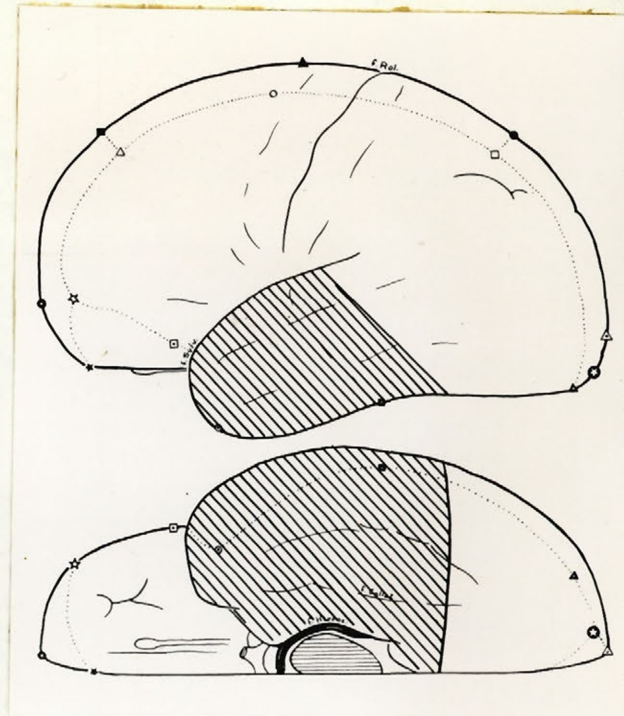

Fig. 2 Large left temporal removal.

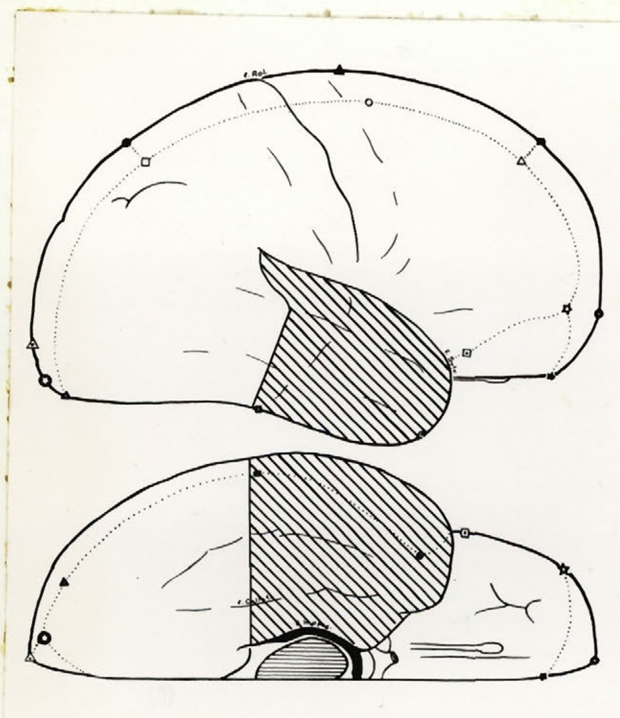

Fig. 3 Right temporal removal, sparing posterior ventral surface.

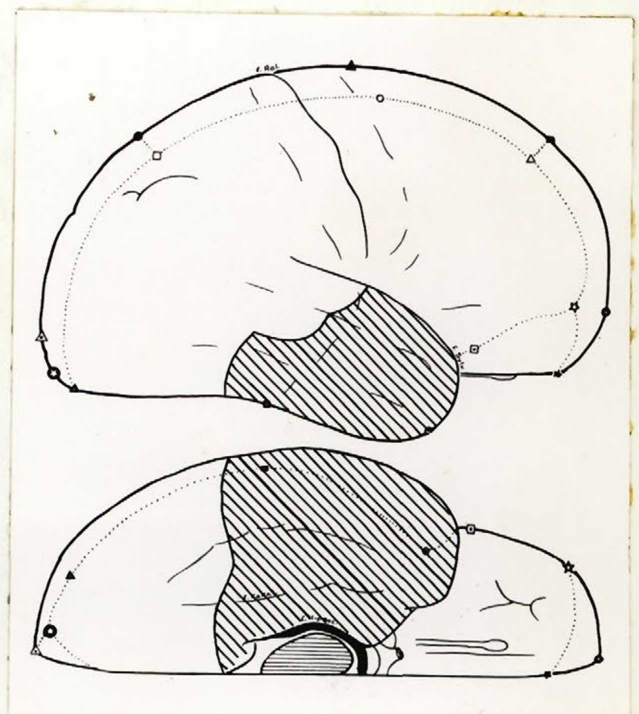

Fig. 4 Right temporal removal, sparing part of the first temporal convolution.

the various groups on this test; after operation the left temporal-lobe group improved significantly compared with other brain-damaged groups (P .01). The normal control group was too small to tell whether this result should be interpreted as a genuine improvement in the left temporal group, or as a normal practice effect which other patients failed to show. The extremely cautious attitude of these patients after operation is consistent with an improvement in accuracy on this test.

THE VISUAL AND TACTUAL DEFICITS WITH TEMPORAL-LOBE LESIONS

It will be recalled that selective ablation studies in the monkey show that there is an area on the ventromedial aspect of the temporal lobe which has important visual functions. The results of the present investigation suggest that the same is true of man. Both the right and left temporal-lobe groups showed a significant visual deficit, and the area of maximum abnormality in most patients was on the mesial and inferior surfaces of the temporal lobe. There was no indication of deficit in the case of two patients who had damage to the lateral surface only, with subsequent excision of the first temporal convolution. The visual data, then, agree substantially with the animal studies. However, the discovery of a tactual deficit with damage to the right temporal lobe points to a difference between man and monkey, since no comparable deficits have been seen in monkeys with damage restricted to the temporal cortex. This may mean, as Penfield (1935) has suggested, that in the human cortex, as compared with that of lower primates, there has been a posterior and inferior migration of somaesthetic function; or, it may mean that the presence of abnormally functioning tissue in the temporal lobe affects a wide area of posterior cortex.

We turn now to examine the nature of the visual deficit seen with damage to either temporal lobe. This deficit is not attributable to visual field defects, since it is present before operation,when visual fields are unimpaired. (Also, one patient showed marked field defects after a parietal-lobe excision, yet had no difficulty with any of the visual tests of this battery.) The interesting point is that the temporal-lobe deficit occurs with two tests only, both of which deal with pictorial representations of scenes of everyday life. Yet the deficit cannot be equated to a general loss of "social intelligence", since no defect was seen on the Verbal Situation Test (apart of course from the disturbance seen in the left temporal group during recovery from aphasia), and this test is also designed to measure some kind of social awareness. It seems then that we are dealing specifically with an impairment of complex visual perceptions.

However, a comparison of the visual tests which showed deficit in both temporal-lobe groups with those which did not, makes the nature of this specifically visual loss hard to define. The fact that no disturbance was found with the Picture Analogies or the Progressive Matrices tests, both of which demand an obvious effort of concentration and are often considered arduous by normal subjects, shows that the problem is not one of motivation. The lack of disturbance on the Wechsler Picture Completion subtest also shows that there is no gross inability to recognise outline drawings of people and things. It seems rather that the deficit appears when attention has to be given to many aspects of a complex picture, or when different pictures have to be arranged in a meaningful order on the basis of slight differences of detail. Visual discriminations of this kind are well practised in our culture, but they may be difficult to acquire in the first place. It is clear that much more experimental work is needed before we can identify the important factors making these tests difficult for patients with temporal-lobe damage. The schematic nature of the drawings, the presence or absence of social anomalies, and the mode of presentation of the test may all prove to be important.

The inferiority of the right temporal-lobe group compared with the left on tests of spatial relationships, visual and non-visual, provides support for those who contend that the right posterior association cortex is more implicated than the left in such tasks (McFie, Piercy and Zangwill, 1950; Hécaen, Ajuriaguerra, and Massonnet, 1951). Earlier work has, however, been specially concerned with the functions of the right parieto-occipital cortex, and in directing attention to the right posterior temporal region, the present study strikes a comparatively new note. Hebb's (1939a) report of similar deficits in a single case of right temporal-lobe removal is of course in perfect agreement with the results of the present investigation.

It is possible that some objection will be raised to interpreting the results of this study as proving the greater importance of the right hemisphere for tests of spatial ability. It may be suggested that the striking differences between the right and left temporal-lobe groups are simply due to the excisions on the left being smaller (due to the danger of invading the primary speech area in the posterior part of the left temporal lobe). This argument can be refuted on two counts. First, the inferiority of the right temporal group was apparent before operation, and there is no reason to think that the pre-operative disturbance was greater in the right-sided group. Secondly, though the removals on the right were on the average greater than on the left, two of the left-sided removals (one of which is illustrated in Figure 2) were as great as any on the right, and both these patients showed superior ability on the spatial patterning tests. If we consider the left temporal-lobe cases as a whole, we find no relationship between post-operative efficiency on these tests and size of removal. We may therefore conclude that the right temporal lobe is more implicated than the left in spatial ability.

The results suggest that the posterior temporal region on the right is more important than the anterior region in these spatial tests, but this may be merely a question of the size of lesion. There were no instances of posterior removal alone. It is interesting to note that a tactual disturbance similar to that seen in the right temporal cases of the present study also occurred after operation in one case of complete right occipital lobe removal, in which there was some invasion of the posterior temporal cortex.

The clear-cut deficits in the temporal-lobe group before operation are a remarkable testimony to the detrimental effects of long-standing cerebral abnormality. It has already been pointed out that the greatest abnormality was usually found in the region which animal studies have specifically implicated in visual functions. Attempts to relate the results to electroencephalographic data failed. Not all patients showed continuous electrographic abnormality before operation; on the contrary, it was sometimes necessary to give the patient metrazol in order to locate the source of his attacks. It seems reasonable to expect that these patients would be most likely to show impairment after operation, but this was not so. Again, it might be thought that where seizures were frequent and electrographic abnormality severe and widespread before operation, the converse might occur, and the patient actually improve after operation. This was most convincingly demonstrated in the case of two patients with huge removals in the right hemisphere, but it did not occur in any of the patients of the present study, with their relatively restricted removals of temporal, parietal, or frontal cortex.

The fact remains that retesting was carried out comparatively soon after operation, and follow-up studies on patients whose epilepsy has been cured may show general improvement compared with the pre-operative level. At present, the finding of marked intellectual defects before operation which are not greatly changed by the removal of the pathological lesion and surrounding normal tissue, together with the apparent lack of relationship to the degree of electroencephalographic abnormality, present a baffling problem for further research.

SUMMARY

A battery of sixteen tests was given to a group of patients before and after surgical removal of epileptogenic foci in temporal, parietal, or frontal cortex. The purpose of the investigation was to compare the test performance of the temporal-lobe group with that of other subjects, and, secondly, to compare right and left temporal-lobe groups. The results showed, first, that before operation the temporal-lobe patients were significantly inferior to the frontal and parietal control patients on two visual tests (the McGill Picture Anomaly Series and the Wechsler Picture Arrangement subtest), both of which involve complex picture material dealing with everyday social situations. There was also a marked inferiority of the right temporal-lobe group on tests of spatial patterning, visual and non-visual. These differences were present before operation, but were intensified after removal of the temporal lobe, a significant further loss being observed in the right temporal group on one test of block design.

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