Some tests of the "Sensory Disinhibition" explanation of the psychological effects of frontal lobe damage in man.

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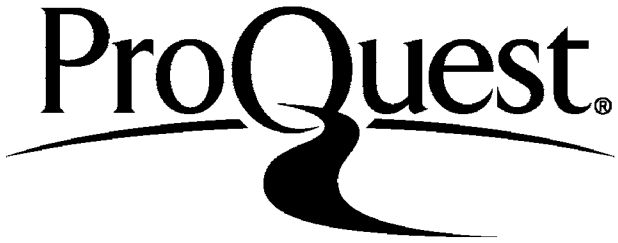

Abstract

Studies of the effects of frontal lobe lesions in animals and man were discussed in relation to hypotheses of frontal lobe function. It was suggested that the "Sensory Disinhibition" hypothesis provides the most useful account of the results of the animal experiments. According to this hypothesis, the deficits resulting from frontal damage are due to a disturbance of attention, brought about by interference with a neurophysiological system which controls the selective inhibition of sensory input. The review of human studies suggested that the sensory disinhibition hypothesis could provide the basis for an explanation of the wide range of impairments produced. To explore this possibility, six experiments were carried out, comparing patients with frontal lobe lesions with those having temporal lesions on tasks concerned with selective attention. In some experiments, data from normal control subjects were also obtained. Experiment 1 (Discrimination Learning) indicated that frontal subjects differed from temporals and controls in accordance with the predictions of the sensory disinhibition hypothesis. The results of Experiments 2 (Visual Search) and 3 (Classification), however, suggested no selective effects due to locus of lesion. In Experiments 4, 5 and 6, the "post-search error", a measure distinguishing frontals from temporals in Experiment 1 and thought to reflect "sensory disinhibition", was correlated with the performance of each of the two clinical groups. There was some evidence in Experiments 4 and 6 (but not Experiment 5), of a correlation in the frontal group. It was concluded that the experiments provide only moderate support for the sensory disinhibition hypothesis in relation to the effects of frontal lobe damage in man.

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Introduction

Investigations of the psychological effects of cerebral damage continue to occupy a prominent position in Psychology and have led in recent years to the emergence of the hybrid discipline of "Neuropsychology". While the clinical importance of being able to predict the particular deficits which are likely to result from particular lesions has always been acknowledged, it is now more widely recognized that an additional value, in cases of cerebral dysfunction, lies in the opportunity to make inferences about the underlying mechanisms which may have been disturbed.

In primates, the term "frontal lobe" refers generally to the area lying rostral to the central (Rolandic) sulcus. It includes structures lying above the lateral (Sylvian) fissure and is bounded by a line which continues the central sulcus on to the medial and basal surfaces of the hemisphere (Chandler Elliott, 1969). A widely accepted subdivision distinguishes between "motor" and "premotor" regions, i.e. areas which, in terms of muscular contractions clearly respond to electrical stimulation, such as Brodmann's area 4 which lies within the precentral gyrus, and those which do not, in particular the "prefrontal" areas 9, 10, 11 and 12. Cytoarchitectural and other anatomical evidence supports this distinction. In general the prefrontal regions have a distinctly granular appearance

microscopically, in contrast to the agranular structure of areas lying closer to the central sulcus. The granular cortex also receives projections from the dorsomedial nucleus of the thalamus, whereas agranular cortex is supplied by projections from the ventrolateral nucleus. An additional characteristic of granular cortex lies in its extensive efferent connexions with other cortical and subcortical regions.

Phylogenetically the frontal granular cortex achieves maximum structural complexity in primates, especially man. In fact comparative cytoarchitectural studies appear to show that the prefrontal cortex has no direct counterpart in nonprimates (Nauta, 1971). In view of this, most studies of frontal lobe function have been concerned with the investigation of the effects of prefrontal lesions in primates.

Such considerations give rise incidentally to the question of the extent to which continuity of cerebral function is to be expected between species. The principal difficulty arises when attempts are made to compare, and possibly generalize from, results obtained from different species of primate. Recent writings (e.g. Morris, 1967) have popularized the notion that man is little more than a neatly dressed (or undressed) ape, and no doubt many behavioural, neuroanatomical and other similarities can be demonstrated. Other writers (e.g. Lenneberg, 1967) however

have minimized such continuities, referring in particular to man's unique (pace Sarah: Premack, 1970) capacity for language, and the fact that he lives in a highly evolved and complex culture (e.g. Bruner, 1966). After a careful review of comparative neuropsychological research on man and monkey, Drewe et al. (1970) concluded that there were enough discrepancies for considerable caution to be needed in generalizing from monkey to man in such research. For example, bilateral damage to the hippocampus in man produces a severe and permanent deficit in the acquisition of nearly all types of new information (Scoville and Milner, 1957), a result which is not paralleled by comparable research on monkeys (Douglas, 1967; Isaacson, 1972). Weiskrantz (1961) has emphasized the necessity for reasonable equivalence of function to be present in various species before the effects of cortical damage can be compared properly. A lesion placed in a particular area in one species may produce, for example, an impairment of visual function not found in another species. This may be due, however, to a relatively greater reliance on visual skills in the first group of animals compared with the second. In general, it is now thought that comparative studies of the chimpanzee may be more appropriate particularly in view of recent evidence that, phylogenetically, this species is probably more closely related to man (Doolittle and Mross, 1970), and may even be capable of acquiring linguistic skills (Premack, 1970).

Although this is undoubtedly an important issue, and especially relevant to the present study which derived principally from work conducted with nonhuman primates, it should not be allowed to assume an unreasonable degree of prominence. In the review which follows, therefore, studies of a variety of primates and other animals will be included. Also, as the investigations to be reported later are concerned specifically with the frontal lobes, studies which relate mainly to other areas of the brain will only be referred to when they are considered directly relevant. This is a matter of expedience, and in no way implies a view of the brain as comprising a set of isolated functions which never interact.

Chapter One

Animal Studies

(a) The Delayed Response deficit

The most reliable and well documented result of frontal damage in the monkey is the severe impairment found on the "delayed response" and "delayed alternation" tests (Jacobsen, 1936; Jacobsen and Nissen, 1937). In the classical versions of these, discussed originally by Tinklepaugh (1928), and used by Jacobsen, the subject is rewarded for remembering the position of a container which was previously "baited" with food, over a given period of time during which two identical containers are obscured by an opaque screen. In delayed response a reward is given when the subject makes the correct response to the appropriate container, whereas in delayed alternation it is only provided if he responds to the container or cue which was not associated with reward on the previous trial - hence the "alternation".

The delayed response deficit is not restricted to the visual modality (Iversen, 1967; Passingham and Ettlinger, 1972; Weiskrantz and Mishkin, 1958). However it does tend to be exceptionally marked in rhesus monkeys, whatever the method of testing (Divac and Warren, 1971). Comparisons between different species are of course difficult but do seem to indicate that impairments on delayed response are generally less severe and permanent

in dogs (Konorski, 1961), cats (Divac, 1968; Divac and Warren, 1971; Wikmark and Warren, 1972) and, more significantly, chimpanzees (Blum, 1948; Rosvold et al., 1961). These differences are not well understood and suggest that task variables are probably important in the effects of frontal lobe damage in different species.

Because an element of delay is incorporated into both, the delayed response and delayed alternation tests are often thought to be sensitive to the same underlying behavioural processes. It may be simply that in delayed alternation the cues are more distinctive as they arise from the animal's motor behaviour. The extent to which the two may be used interchangeably as equivalent measures of the frontal lobe deficit however has been questioned. For example normal infant monkeys achieve adult levels of performance on delayed response earlier than delayed alternation (Goldman, 1971). Goldman et al. (1970a) performed prefrontal lobectomies on infant and juvenile rhesus monkeys and examined their performance on delayed response and delayed alternation problems. The results showed that whereas none of the animals was successful on delayed alternation, all but one achieved criterion on delayed response, although significantly more slowly than controls. This suggests at least that the former is more difficult. On the other hand if separable neural mechanisms within the frontal lobe are associated with

each, selective lesions of frontal cortex have provided no evidence that to all intents and purposes the two tests are not equivalent. Moreover in the Goldman *et al.* study, the delay was increased gradually over a series of trials in the delayed response problem, a procedure which, there is some suggestion, may be generally conducive to greater proficiency in frontal animals (Harlow *et al.*, 1952). This therefore may have been responsible for the differences between delayed alternation and delayed response performance.

In Jacobsen's original study (1936), only bilateral frontal lobectomies affected performance. Gross and Weiskrantz (1964) however claimed that lesions in and around the *sulcus principalis* produce a greater deficit on delayed response and delayed alternation tasks than other laterally placed lesions (see Figure 1). Moreover there is evidence that an impairment will follow damage to *sulcus principalis* only if the animal is required to perform a task with an intra-trial delay.

For example, Stepien and Stamm (1970a,b) compared groups of rhesus monkeys which had received different types of lesion within the frontal lobe. The animals were tested in an open field apparatus rather than the conventional Wisconsin General Test Apparatus (WGTA) which is usually employed. Two foodcups were provided, as in the WGTA, one near each of the two cues involved,

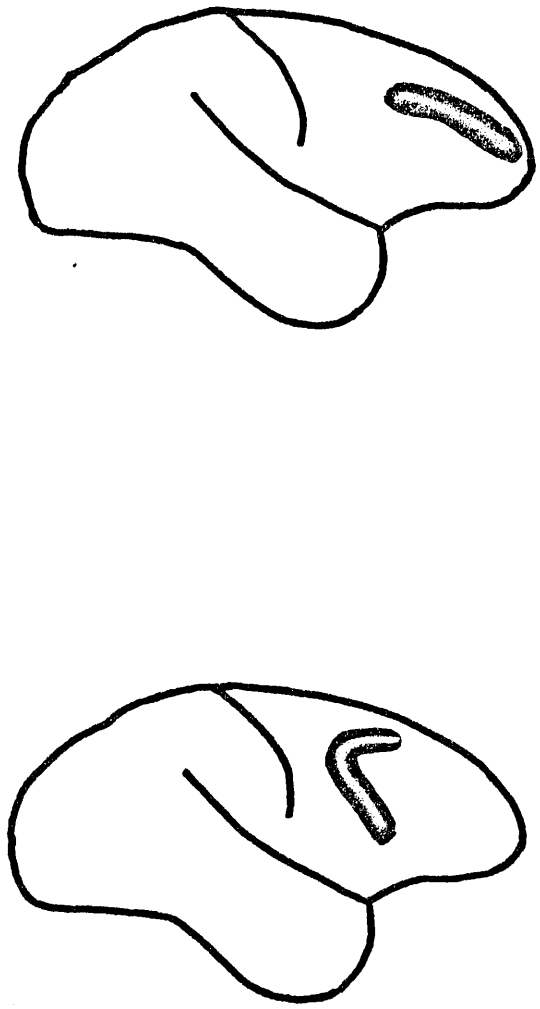

Figure 1. Typical lesions of sulcus principalis (above) and sulcus arcuatus (below) in the rhesus monkey

but the monkeys were actually taught to approach the foodcup opposite to the cue which was illuminated, and to retrieve a peanut. After training to criterion, selective frontal lesions were carried out and post-operative retention subsequently examined. A comparison of conditions in which an intra-trial delay of 5 seconds was used, and of those where it was not, suggested that lesions limited to the banks and depths of sulcus principalis caused an impairment only where there was a delay. Unfortunately no statistical support for this was provided.

Goldman and Rosvold (1970) also used rhesus monkeys to examine the effects of lesions placed in different parts of the frontal lobe on performance in tasks with and without intra-trial delay. The animals learned two tasks to criterion. The first, a "conditional position response" task, required them to respond to the left or right depending on the source of an auditory cue. No delay was employed. The second was a conventional delayed alternation problem in which the animals were trained to displace identical coloured plaques alternately from the right and left foodwells. Animals with lesions restricted to the depths and banks of sulcus principalis were impaired on the latter but not the former, when tested postoperatively, while the reverse was true of animals with lesions of sulcus arcuatus (see Figure 1). This

suggests once again that sulcus principalis must be intact for successful performance in tasks which contain an element of delay. On the other hand, it is unfortunate that Goldman and Rosvold chose to compare a task which necessitates alternation of responses (delayed alternation) with one which does not, as this introduces an additional confounding variable. That is, it may have been the alternation requirements rather than the delay features which produced the deficit in the sulcus principalis group in this experiment.

An electrophysiological study reported by Stamm (1969) also implicates sulcus principalis in delayed response performance. Stamm used a multiple electrode implantation technique to study the effects of electrical stimulation administered during specified portions of a delayed response task in four monkeys. Unilateral prefrontal ablations were first of all carried out and then up to four electrodes were inserted in rows, straddling sulcus principalis in the intact hemisphere. Stimulation was applied at constant voltage settings and lasted for four or two seconds. An intra-trial delay of 8 seconds was used. The animals performed at only chance level when the current was applied during the first few seconds of the delay interval, although there was also some suggestion of an impairment when it was administered during the final second of cue presentation or the last four

seconds of the delay. Stamm's results also point to the importance of the caudate nucleus in delayed response performance, since electrical stimulation here resulted in chance level performance when applied at any stage of the delay. This concurs with the results of previous research on caudate nucleus lesions in monkeys (Divac et al., 1967; Rosvold and Delgado, 1956; Tucker and Kling, 1969) and cats (Divac, 1968). In fact Divac (1968) found that a combined prefrontal cortex and anterior caudate lesion resulted in no greater impairment than an anterior caudate lesion alone.

In attempting to isolate the causes of the failure of animals with frontal lesions to solve delayed response and delayed alternation problems, many investigators have modified and extended the two test paradigms in a number of different ways. In the classical version of the tests, successful performance depends upon spatial or positional cues. In the "delayed matching to sample" technique however, the cues are nonspatial and the animal has to learn to select a previously reinforced object from among a number of distinctive alternatives following a delay. And in the nonspatial version of delayed alternation, "object alternation", the animal is trained to respond to one of a number of cues or objects, following which the reward is withdrawn and only reintroduced when the animal responds to another cue selected by the experimenter

according to a systematic schedule. The use of these related paradigms has proved extremely useful in the analysis of the effects of frontal lobe lesions.

In view of the apparent simplicity of tasks such as delayed response and delayed alternation, and despite the regularity with which the frontal animal's deficit on such tasks may be elicited, the isolation of the causes of the impairment has proved more difficult than might be imagined. One reason for this probably stems from the fact that the delayed response task comprises at least three separate stages, and the defective performance could therefore arise from a disturbance at any of these. The stages are those of (a) cue presentation, requiring registration, (b) intra-trial delay, requiring storage, (c) response execution, requiring retrieval. A study reported by Buddington et al. (1969) attempted to decide which of these stages were more likely to be the sources of the frontal animal's difficulties but there was no clear cut evidence that disruption of any one of them was necessary or sufficient for an impairment in squirrel monkeys. It is thus not surprising that a variety of hypotheses has been offered to explain the delayed response deficit. These are discussed below.

(b) Hypotheses concerning the causes of the delayed response decifit

The most obvious interpretation of the delayed response deficit is that some sort of memory impairment is involved. In fact Jacobsen (1936) attributed the failure of his animals to a disturbance in "immediate memory", since he found no impairment at zero delay, but it is clear that he regarded this interpretation as less than satisfactory. The presence of an intra-trial delay however has been shown to be neither necessary nor sufficient for a behavioural deficit to occur after frontal lesions. Buffery (1964,1967) compared baboons which had received frontal and temporal lobe lesions with normal controls on a series of matching and object alternation tests with and without delay. Although performance improved with decreasing intra-trial delay, there was a significant residual deficit at zero delay. Similar results have been obtained for tactile discrimination problems in baboons (Iversen, 1967) and monkeys (Passingham and Ettlinger, 1972). The introduction of a delay therefore might be said to exacerbate an underlying discrimination learning deficit which is elicited by certain types of discrimination problem. That intra-trial delay is not a sufficient condition for postoperative impairment is shown by many studies which demonstrate that in certain experimental conditions animals with frontal lesions can perform successfully in delay tasks. Such conditions have included keeping the animal in the dark

during the delay period (Malmo, 1942), the administration of tranquillizing drugs (Pribram, 1950), the provision of reinforcement before the onset of the delay (Finan, 1942), the use of novel pairs of cues for each trial (Meyer et al., 1951), the interpolation of a delay after each pair of Right-Left responses in delayed alternation (Pribram and Tubbs, 1967), and the use of the go-no-go variety of delayed alternation (nonspatial delayed alternation) in which the animal has to withhold its response to a single foodwell on alternate trials (Mahut, 1971; Mishkin and Pribram, 1956). Modifications of the classical delayed response and alternation procedures have also eliminated the hypothesis that successful performance depends upon the appropriate "orienting" or postural response made at the beginning of the trial and maintained during the delay period, and that the ability to do this is disturbed in frontal damage. It is difficult to see how this hypothesis could be applied to situations in which the cues are not spatial and moreover, frontal damage appears to lead if anything to an increased reliance on the use of such postural cues in delay problems (Stamm, 1970).

There is some evidence that animals with dorsolateral frontal lesions can handle nonspatial alternation and delay tasks more effectively than those which depend upon the use of the spatial location of the cues such as the classical delayed response and delayed alternation problems. Drawing

together several lines of evidence, Mishkin et al.(1969) proposed that frontal lesions may therefore result in two quite separate behavioural impairments which contribute independently to the deficit observed on delay problems. The first of these, a "perseverative factor", derives from studies reported by Mishkin (1964) which suggested that frontal animals have difficulty in overcoming various learned and natural preferences and aversions for objects. Perseveration is a frequently noted sympton of frontal lobe damage and a disturbance of inhibitory function has sometimes been singled out as the source of the frontal lobe deficit (e.g. Brutkowski, 1964; Stanley and Jaynes, 1949). The second factor is concerned with the use of spatial cues. This "spatial factor" is not clearly defined but presumably refers to the processes involved in the registration and storage of information relating to the arrangement of the relevant cues. In object alternation therefore, which does not require the use of spatial information, the only source of difficulty is presumably that deriving from the "perseverative factor".

Mishkin et al. (1969) argue that the two factors are organized independently in the frontal cortex, damage to the orbital surface resulting in interference from the perseverative factor, while damage to the dorsolateral surface produces a deficit in the processing of spatial cues. There is evidence to support this distinction. For example monkeys with orbital lesions may be reliably differentiated

from those with dorsolateral damage on the basis of response latencies, which are longer after dorsolateral lesions (Passingham, 1972a), and perseverative errors in "reversal shift" problems which are more frequent after orbital lesions (Passingham, 1972b). Mishkin et al. compared groups of monkeys with selective lesions of the frontal lobe and found that one group with prefrontal lesions, which excluded ventrolateral cortex, was able to relearn a preoperatively acquired object alternation task whereas another similar group failed on spatial alternation. Animals with damage to the orbital surface were unable to relearn either problem. The implication is that the two groups which failed on spatial alternation did so for different reasons, those with orbital lesions because of abnormal perseverative tendencies and those with dorsolateral damage on account of a disturbance in the "spatial factor". Animals with dorsolateral lesions were presumably more successful on the object alternation task because of its nonspatial requirements. Unfortunately no real statistical support for these conclusions is provided.

Butter (1969) also compared groups of rhesus monkeys with various lesions of the frontal lobe on a spatial and a nonspatial problem. In this study animals were taught two reversal tasks, one requiring a response either to the left or right and the other involving a simple object discrimination. After reaching a criterion level of performance, reinforcement was switched to the cue which

had previously been negative, this procedure being continued until five such reversals had taken place. An analysis of the results in terms of the animals' perseverative errors showed there was a much higher level of these on the spatial problem for the dorsolateral group compared with orbitals. Error rates for the object discrimination reversal however were significantly higher for the orbital animals, confirming Mishkin's "spatial deficit" hypothesis. Butter also found animals with orbital lesions slower to extinguish a bar press response, a result which is consistent with the view that such damage produces a deficit in response inhibition resulting in perseverative behaviour. In passing it may be noted that Pavlov found that extinction of the conditioned response did not take place after removal of the frontal areas.

Another hypothesis which distinguishes between the effects of orbital and dorsolateral frontal damage was proposed by Goldman et al. (1970b). There is good evidence that lesions which are restricted to the dorsolateral cortex are not followed by the usual delayed response deficit when infant monkeys as opposed to adults are used (Akert et al., 1960; Harlow et al., 1964; Tucker and Kling, 1967), although it may still be elicited if a total prefrontal lobectomy is performed (Goldman et al., 1970a). This led Goldman et al. (1970b) to suggest that therefore there may be compensation of function in the case of dorsolateral, but not orbital, cortical damage. An experiment

consistent with this hypothesis is reported which showed that infant monkeys with prefrontal lobectomies were able to perform as well as normals on the "conditional position response" (see p. 13), but were significantly impaired on an object discrimination reversal problem. The inference is that effective performance on the conditional position response task may be possible after dorsolateral lesions, due to compensation, but that this is not true of the functions served by the orbital cortex which are disturbed by orbital injury, as indicated by the discrimination reversal impairment.

However, not all reported investigations support the hypothesis of a dissociation of impairments within the frontal lobe. Warren et al. (1969) found no evidence of defective spatial alternation performance in rhesus monkeys with unilateral frontal lesions of dorsolateral cortex whereas the typical delayed response deficit was observed. Butler and Eayrs (1969) reported a total absence of post-operative impairment in monkeys with orbital frontal lesions, and Goldman and Rosvold (1970) found only a delayed alternation deficit in animals with dorsolateral damage, which they interpreted to mean that a delay must be present before the "spatial deficit" can be elicited. There are additional problems. For example it is unfortunate that perseveration is thought both to follow orbital damage, and yet also be a measure frequently taken after other types of frontal lobe lesion. (In fact perseveration was first noted

with laterally, not orbitally, placed lesions.) The difficulty stems largely from the fact that only two-choice discriminations are usually involved in the typical delayed response and delayed alternation problem. This means that when an animal is not responding to the correct cue it is necessarily producing "perseverative" responses. If dorsolateral damage causes a spatial deficit it should be possible to assess this independently of the animal's "perseverative tendencies". The problem is illustrated by the work of Stepien and Stamm (1970a) described previously. They found little evidence of an impairment following orbital frontal damage but a pronounced deficit in animals with dorsolateral lesions. This impairment derived principally from a tendency, described as a "magneto-reaction", to respond to the visual stimulus itself rather than the appropriate foodcup. Now it could be argued that if perseverative responses result from an abnormal attachment to dominant visual stimuli, and if this were the source of the animal's difficulties, then this behaviour would seem more characteristic of the "perseverative factor" than of an inability to process spatial cues, which is what Mishkin et al. (1969) believe it to be. A separate point is raised by Buffery (1964): perseveration may be a response to rather than the cause of difficulty, since it is found in normals, and also with damage to other areas of the brain when a difficult situation is encountered. There is reasonable evidence for a distinction between the orbital and

dorsolateral deficits discussed above; however the basic mechanisms which are disturbed have not really been described in sufficient detail to permit thorough testing of the hypotheses, particularly in the case of the "perseverative factor".

A more detailed argument for a spatial deficit has been provided by Konorski (1967). He suggests that the prefrontal regions are necessary for the integration of spatio-kinaesthetic information particularly in motor tasks which do not depend on the use of distinctive external cues. In classical delayed alternation, for instance, kinaesthetic information from the previous trial must be retained so that the appropriate response can be made on the next. If the capacity for registering and discriminating such signals is reduced or disturbed in any way an impairment of delayed alternation is to be expected.

Stamm (1970) proposed that if learning a delayed alternation task depends upon the appropriate use of kinaesthetic information, then making this more distinctive or vivid should facilitate performance in intact animals. Conversely, the more distinctive the kinaesthetic cues provided during learning, the greater should be the delayed alternation impairment following frontal lobe damage. Stamm tested the delayed alternation performance of groups of monkeys in three different sorts of apparatus such that the degree of involvement of effector systems and thus the amount of kinaesthetic feedback was varied. These were the

conventional WGTA, a restraining chair constructed so that the animal could move only its preferred hand, and a locomotor maze which required the animal to walk alternately through two doors situated side by side to obtain a reward. The animals were tested pre- and postoperatively and a number of visual discrimination tasks were also included. Preoperative results showed that the delayed alternation problem was learned most rapidly in the maze and slowest in the chair, while postoperatively the error rates indicated least successful performance in the maze, findings which are consistent with Stamm's (and Konorski's) hypothesis. There was no postoperative impairment on the visual discrimination problems.

Similarly, Gentile and Stamm (1972) proposed that the provision of supplementary proprioceptive information should improve delayed alternation performance in frontal animals. Rhesus monkeys with dorsolateral lesions were tested on several types of delayed alternation problem in which the shape of the cues (wooden blocks), the direction of movements involved and the effort required to move the blocks were all varied. The intention was to provide additional distinctive forms of kinaesthetic cue. The results did suggest an improvement in delayed alternation performance in all conditions although only animals with lesions restricted to <u>sulcus principalis</u> showed an improvement in the force variation conditions. This latter result may be related to findings reported by Passingham

and Ettlinger (1972) who examined the performance of rhesus monkeys with various types of cortical lesions on a tactile discrimination learning problem. Compared with those with dorsolateral lesions, animals with orbital frontal lesions were significantly more impaired under conditions of no manual effort which presumably were those of minimum supplementary kinaesthetic feedback. These results do not support Mishkin's spatial deficit hypothesis which postulated that the most damaging lesions would be dorsolateral. (Konorski's hypothesis does not refer to specific areas within the frontal lobe and there was no orbital group in the Gentile and Stamm study.)

One important conclusion from these studies is that there does not have to be a delay for a "frontal lobe deficit" to be elicited, and, moreover, if there is one the animal with frontal damage can learn to cope with it. This means that other factors are responsible for the frontal animal's difficulties.

(c) Evidence for the "sensory disinhibition" explanation of the delayed response deficit in animals

Grueninger and Pribram (1969) compared the performance of normal and frontally lesioned rhesus monkeys in a task which required them to press two panels in sequence. Pressing the first resulted in one of 16 other panels being illuminated from behind, and when this itself was pressed the animal

received a reward. The effect of presenting extraneous visual or auditory stimuli immediately after the animal's response to the first panel was examined by measuring response latencies to the second panel. The results suggested that frontal monkeys were more distracted by these irrelevant stimuli than the normal controls, although there was some evidence that habituation to the stimuli did take place over trials. Similar results were reported by Orbach and Fisher (1959) who investigated the effect of introducing light stimulation during the intra-trial delay period of a standard delayed response task. Preoperatively this had no effect on performance but after frontal lesions had been carried out there was a marked deficit compared with conditions in which no light was present.

This type of effect has frequently been reported in animals which have sustained lesions of the frontal lobes, and the expressions "stimulus-bound" behaviour (Goldstein, 1944), and "magneto-reactions" (Stepien and Stamm, 1970a,b) have been used to refer to the general restlessness, characteristic increase in locomotor activity and unusual responsiveness to external stimuli which typically develops. Weiskrantz *et al.* (1965) suggested that an animal with frontal lobe damage suffers from "an excessive and inappropriately ordered intake of sensory input", and there is evidence that frontal monkeys tend to search for a hidden reward in a much more random fashion than normals (Meyer and Settlage, 1958).

In addition there is good evidence from a number of studies that animals with frontal damage are particularly sensitive to novel forms of stimuli. Gross (1963) studied the locomotor activity of monkeys with frontal lesions under various conditions of stimulation. Maximum reduction of overall activity occurred under conditions of novel auditory and tactile stimulation whereas activity levels were increased when familiar auditory stimuli were presented. Pribram (1961) examined the performance of monkeys with frontal lesions in a series of multiple choice visual discrimination tasks in which the number and novelty of the discriminanda were constantly varied. Since reinforcement was associated with each stimulus on a systematic alternating schedule both novel and familiar stimuli were rewarded at one time or another. The results showed an overall impairment for the frontal which consistently took significantly longer than the other operated (temporal) and unoperated control groups to reach criterion after the reward had been switched from one cue to another. When trials on which novel stimuli occur are considered alone however, the results show that frontal animals respond more rapidly than controls whose behaviour appears more variable. This suggests that where novel cues were present the effect of frontal lobe damage was to lead to a paradoxical improvement in performance.

The most extensive studies of the effects of novel stimuli on the behaviour of animals with frontal lesions are probably those reported by Buffery (1964,1967). In these

experiments the performance of baboons with frontal and temporal lobe lesions was examined in a series of "matching to sample" and multiple object visual discrimination tasks. In the matching problems the animals were presented with five panels, one at each corner of the apparatus and one in the centre. The stimuli were translucent coloured panels, one of which (the "sample") was presented at the centre and also duplicated at one of the surrounding positions. The animals were taught to press the sample and then this "matching" panel to obtain a reward. Both the number of incorrect alternatives appearing in the remaining panels, and also the delay between the presentation of the central sample stimulus and the match stimuli were varied. Compared with animals with temporal damage and unoperated controls, animals with frontal lobe lesions made significantly more errors as the number of alternatives was increased. The impairment was more pronounced in the delayed matching conditions but was nevertheless present with no delay. Frontal animals also took longer to respond to the "sample" stimuli while temporals took longer to respond to the matching stimuli. The frontal animals' difficulties therefore may be said to derive from problems at the initial "registration" stages in contrast to those of the temporals which suggest a retrieval difficulty. Buffery also varied the relative probabilities of various stimuli being presented and found that frontal animals made a greater number of correct matches to the less frequent sample stimuli.

The aim of the object discrimination experiments carried out by Buffery was to examine the effect of varying both the number and novelty of the incorrect alternatives. This was achieved by studying the performance of the animals on six variations of a multiple object discrimination problem. The animals were taught to displace objects covering foodwells which contained a reward. As soon as they had learned to do this with one object present, a different one was introduced (but never rewarded). Once this discrimination had been mastered a third (unrewarded) object was added, and so on, until eight objects were present. Position was randomized throughout. In some of the tasks, all the additional unrewarded objects were identical while in others they were all different from each other. Also in some tasks whenever the number of incorrect stimuli was increased the requisite number consisted of an entirely fresh set of objects, "old" incorrect objects being withdrawn. In three of the tasks the correct object remained the same throughout, while in the remainder a new one was introduced each time the number of alternatives increased. The structure of the six problems is set out below where each letter represents a different object.

Task One

	First discrimination Stimuli		Second discrimination Stimuli	
	Positive	Negative	Positive	Negative
Day 1	A		A	B
Day 2	A	B	A	B B
Day 3 etc	A	B B	A	B B B

Task Two

	First discrimination Stimuli		Second discrimination Stimuli	
	Positive	Negative	Positive	Negative
Day 1	A		A	B
Day 2	A	B	A	B C
Day 3 etc	A	B C	A	B C D

Task Three

	First discrimination Stimuli		Second discrimination Stimuli	
	Positive	Negative	Positive	Negative
Day 1	A		A	B
Day 2	A	B	A	C D
Day 3 etc	A	C D	A	E F G

Task Four

	First discrimination Stimuli		Second discrimination Stimuli	
	Positive	Negative	Positive	Negative
Day 1	A		B	I
Day 2	B	I	C	I I
Day 3 etc	C	I I	D	I I I

Task Five

	First discrimination Stimuli		Second discrimination Stimuli	
	Positive	Negative	Positive	Negative
Day 1	A		B	I
Day 2	B	I	C	I J
Day 3 etc	C	I J	D	I J K

Task Six

	First discrimination Stimuli		Second discrimination Stimuli	
	Positive	Negative	Positive	Negative
Day 1	A		B	I
Day 2	B	I	C	J K
Day 3 etc	C	J K	D	L M N

The testing procedure was arranged so that the animals' performance was measured systematically over a period of days. On any one day the animals were first of all tested for their retention of the previous day's discrimination (the "Between Days Retention" measure) and then taught the next "stage" of the schedule, i.e. tested with one additional discriminandum present until criterion had been achieved (the "Within Day Learning" measure), as indicated above. The objects were small plastic toys purchased from a Woolworths store and testing was carried out in a modified WGTA.

Animals with frontal lobe lesions had no difficulty as far as "Between Days Retention" was concerned but were

significantly impaired in comparison with temporals and controls in their "Within Day Learning" of Tasks Three and Six as the number of incorrect alternatives increased. These tasks of course provide conditions of maximum novelty and the frontal animals' deficit may be attributed to the fact that they sampled more of the incorrect novel objects than temporals or controls. Very few errors were made on Tasks One and Four, confirming again that the novelty of the alternatives is the important variable, since these tasks represent an increase in the number of alternatives with novelty held at a minimum. The relatively low error rate on Task Four also confirms Pribram's (1961) finding that where a response to novelty is rewarded the frontal animal experiences no difficulties.

Buffery attributed the poor performance of his frontal lobe group to a disturbance in selective attention arising from damage to a "frontal lobe system" which controls and regulates mechanisms of stimulus selection and information processing in primates. In contrast to the "perseveration" hypothesis of e.g. Mishkin (1964), Buffery's interpretation stresses the lack of stimulus rather than response inhibition. An animal with frontal lobe damage is regarded as suffering from an excess of sensory stimulation, which causes difficulty in limiting attention to specific stimuli. Its behaviour is "stimulus bound" and therefore highly susceptible to disruption from external influences, particularly if these are unusual or

novel. One attraction of this hypothesis is that it does not require that intra-trial delay must necessarily be present before a frontal lobe deficit can be demonstrated. Disinhibited sensory stimulation can interfere with the animals' performance at any time and a delay therefore merely provides an additional opportunity for such interference to take place. Moreover, in developing the hypothesis Buffery emphasizes the fact that insofar as the delayed response deficit is demonstrable after frontal lobe injury it is not irreparable. There is ample evidence (referred to earlier, p. 17) that the impairment may be substantially alleviated. It is argued by Buffery (1964) that the basis for the improvement is that the effective modifications of procedure, the darkened interval for example, assist the animal in restricting its attention to the relevant stimulus.

The sensory disinhibition hypothesis is therefore also consistent with Buffery's own findings and particularly with regard to the disrupting effects of novel or unexpected stimuli on the frontal group's performance with and without intra-trial delay. One slightly discrepant finding which may be noted however concerns the effects of a novel stimulus presented suddenly without warning. This was investigated in a follow-up to the matching experiments with the prediction that such a procedure would produce maximum impairment in the frontal group. Contrary to expectation, it was found that only the performance of animals with temporal lobe damage

was impaired. No good explanation for this result was offered, except the possibility that the animals had by this time achieved such a high degree of proficiency and had been tested so extensively that the procedure was insensitive to their underlying deficit.

Chapter Two

Human Studies

When considering studies concerned with the psychological disorders resulting from cerebral injuries in man account should be taken of the considerable diversity of the scope, aims, methods and subject material of these investigations. Reitan (1966,1970) for example distinguishes between "clinically oriented" studies concerned simply with the broad category of "brain damage" and "experimentally oriented" investigations concerned with the identification of more selective effects within specific cortical regions. There is also substantial variation in the aetiology and nature of the lesions involved which can be seen to range from missile wounds and other head injuries of less belligerent origin to damage caused by, and arising during the treatment of cerebrovascular diseases, diffuse atrophic processes, and space occupying lesions such as the intracranial abscess and tumour. As regards the size of the various studies, the relatively large scale investigations of, for example, Kleist (1934) and Goldstein (1942) may be compared with those of Teuber (1964), Milner (1964) and Warrington (1971) and finally with the single case studies of e.g. Nicholls and Hunt (1940) and more recently Luria (1966;1973).

One of the aims of Neuropsychology is the identification of parallel disturbances in man and animals and it is significant that improvements in experimental techniques

and procedures for verifying the anatomical locus of cerebral lesions have meant that, in terms of experimental control, recent neuropsychological studies of man approximate those conducted with animals much more closely. However this should not obscure the fact that in practice there are still important differences. For example animals are usually tested within weeks or months of undergoing surgery. In the case of neurosurgical patients however the postoperative interval is generally much longer, periods of five or ten years being by no means uncommon. Surgical procedures also differ. Animals usually receive extensive bilateral lesions produced by the method of subpial aspiration, whereas in neurosurgical intervention for the relief of tumours or abscesses the damage is far less widespread but may conversely involve deeper cortical and subcortical tissue. Penetrating missile wounds also form a separate category as they tend to produce a characteristic type of cerebral lesion (Newcombe, 1969). This does not mean that comparisons between animal and human studies, and between various types of human study may not be made but simply that special problems are involved in drawing conclusions from them.

Hypotheses concerning the effects of frontal lobe damage in man

(i) The relationship between frontal lesions and intelligence

The effects of frontal lobe lesions in man are not easily defined. Clinically, there is a characteristic mixture of off-handed euphoria and careless indifference which is referred to colloquially (and not very helpfully) as "frontal lobe-ishness". There are no obvious sensory, perceptual or amnesic disorders and in most cases linguistic processes appear to remain intact. Many systematic studies comparing frontal with other cortical lesions have also failed repeatedly to demonstrate any selective impairments due to frontal damage (Teuber et al., 1951; Teuber, 1964). And not surprisingly, in view of this, there is little evidence for the more grandiose "classical" view of the frontal lobe as the "organ of civilization" (Halstead, 1947) and necessary for higher-order "abstract" or "conceptual" cognitive functions. In fact, in well known discussions of this matter, Hebb (1945, 1949) questioned the value of possessing an intact pair of frontal lobes at all, arguing that there were no definitive and adequately controlled studies to demonstrate their value. The relationship between frontal lobe damage and I.Q. is a contentious issue but there can be little doubt that this scepticism was well founded, and even later more systematic studies have provided little support for the idea that the frontal lobes are the seat of intelligence.

This does not mean to say that intelligence test scores are not affected by frontal lobe injury. Two representative studies carried out by Tow (1955) and Hamlin (1970) which are concerned with the long term effects of frontal lobe surgery show significant reductions in intellectual capacity. Tow's main findings were of a significantly poorer postoperative performance on Ravens' Progressive Matrices, and one of Terman's vocabulary tests, when preoperative were compared with postoperative scores obtained one year after surgery. Hamlin (1970) examined the Wechsler scores of a group of psychotics who had undergone either "lower" forebrain (orbital topectomy) or "upper" forebrain (superior topectomy) surgery. Preoperative scores were compared with those obtained 8 and 14 years later. Those who had received superior topectomy were found to have suffered, on average, a loss in intellectual function of about 10 I.Q. points when considered next to the orbital and unoperated control groups. The effect appeared to be progressive, although the greatest reduction had already taken place 8 years after surgery. Scores for the orbital subjects closely match those for the controls, a result which recalls the suggestion discussed in Chapter One that there may be specialization of function within the frontal lobe in monkeys. When performance on the various subtests of the Wechsler is considered separately, most from the Verbal Scale, and Picture Arrangement from the Performance Scale clearly discriminate the superior group

from orbitals and controls. After eight years however no consistent picture emerges.

While of considerable clinical value, investigations such as these are difficult to interpret because of the many complex psychological processes involved in answering an intelligence test and the variety of items included. Until the specific psychological operations embodied in the various subtests are established therefore, no detailed hypotheses about frontal lobe function can really be formulated.

Newcombe (1969) studied a group of soldiers who had sustained missile injuries to the brain during World War II. The subjects were compared on a wide variety of tasks, including Ravens' Matrices. There was no evidence for a generalized intellectual deficit as measured by this test in any of the lesion groups. When compared with those with nonfrontal lesions however, the frontal lobe group did perform particularly badly on a test of "verbal abstraction" (the similarities test of the W.A.I.S.) which required the subjects to answer questions such as "in what way are water and air alike?" This result may be compared with observations reported by Zangwill (1966) that frontal lobe damage produces an impairment on tests of "divergent" thinking in which emphasis is placed on the variety and originality of responses. Such tests are therefore often thought to be measures of different sorts of intellectual abilities from those assessed by conventional I.Q. tests, which traditionally have a high proportion of

"convergent" items. This raises the possibility that the poor performance of Newcombe's frontal group on the similarities test, itself essentially open-ended and divergent (Wallach and Kogan, 1965), was due to a reduction in what may loosely be called the capacity for imagination or originality. If this hypothesis were to be borne out it could be argued that selective impairment of "higher order" processes can be demonstrated in frontal lobe damage though not through the use of conventional intelligence tests. The value of such a demonstration however must depend on the extent to which the validity of divergent thinking tests has been established, and at present this issue is still not resolved (Bolton, 1972).

(ii) Disturbances of learning and memory associated with frontal lesions

Following Jacobsen's suggestion (1936) that the basis of the delayed response deficit found in monkeys following frontal lobectomy is a disturbance in "immediate memory", there have been a number of attempts to test the performance of frontal lobe patients on tasks having an intra-trial delay in order to determine whether a comparable deficit exists.

Ghent et al. (1962) tested the retention of patients with frontal and nonfrontal penetrating missile wounds, and a control group, under conditions of immediate and delayed (15 seconds) recall. With the exception of the Wechsler

Digit Span all the tasks employed were designed to minimize the use of verbal coding of stimuli. Thus the subjects were required to memorize the orientation of an illuminated rod, the position of a luminous dot presented on a standard perimeter, the location of a stimulus applied to the surface of the skin and the amount of body tilt experienced in a tilting chair. In addition Ghent et al. examined the subjects' ability to reconstruct the order in which a series of wooden blocks had been presented. There was no suggestion however of an impairment on any of these tasks under either condition of testing in the frontal lobe group. It may be noted however that in most of the tasks, subjects were tested in the dark or with their eyes closed. This would minimize the effects of interference from extraneous sources which according to the "sensory disinhibition" hypothesis would normally be likely to impair the performance of the frontals.

Lewinsohn et al. (1972) also compared patients with frontal and nonfrontal damage with normal controls on a series of short-term memory tasks. Subjects in this study had sustained lesions of various kinds, mainly of cerebrovascular origin. Memory for visual, auditory and kinaesthetic information was examined under conditions of zero and a 10 second delay with rehearsal minimized by requiring the subject to count forward in intervals of one. The auditory task required the retention of words; most of

the visual material was also meaningful and therefore amenable to direct verbal coding. In the kinaesthetic task the subject was asked to reproduce the length of various lines drawn with a pencil, while blindfold. The results showed that the frontal group were significantly impaired in all tasks except the kinaesthetic although their performance was worst of all the groups on this task as well. There was also evidence of more rapid forgetting between 0 and 10 seconds in patients with frontal lesions.

Prisko (1963) used a delayed paired comparison procedure to study short-term memory in patients with a variety of different brain lesions. This technique requires subjects to decide whether the second of two stimuli presented in succession, separated in most cases by a short interval, is the same as, or different from, the first. In Prisko's experiments auditory as well as visual material was used, with intra-trial delay intervals of up to 60 seconds. The stimuli consisted of a series of auditory clicks, tones, flashes of light, colours, and nonsense figures. Although patients with lesions of the frontal lobe performed satisfactorily on the tones and nonsense figure comparisons, they were found to perform very poorly on tasks requiring the comparison of clicks, flashes and colours under conditions of delay. Prisko also noted that these impairments were present in patients tested many years after surgery and suggested that they should not therefore be regarded as merely temporary postoperative effects.

Both the investigations of Prisko (1963) and Lewinsohn *et al.* (1972) have therefore provided evidence for a deficit in frontal lobe patients on tasks incorporating an intra-trial delay. In neither case, however, has a delay been shown to be necessary nor wholly sufficient for a deficit, a conclusion which is consistent with the results reported for animals. In the Lewinsohn study there was an obvious impairment at zero delay, and in both studies there were tasks where performance was satisfactory even with a delay. It is true that in the Lewinsohn study the performance of the frontal lobe group was only comparable to the nonfrontal group in the kinaesthetic task but these exceptions do raise the question of whether a "memory disorder" can be said to be responsible for these impairments which are present under conditions of delay, and if so, what is the best way of characterizing it.

Recent experimental investigations of the memory disturbances found in, for example, amnesic patients have been based on current psychological models of memory. Much attention has been paid for instance to the question of the extent to which these various disorders arise out of an abnormally rapid fading of the memory trace, a failure to transfer information from a short to a long-term store, or a reduction in storage capacity. One model which provides a similar analysis of the frontal lobe deficit was proposed by Gross and Weiskrantz (1964). They

argued that frontal lesions interfere with the retrieval of information from short-term memory while long-term retention remains intact. Thus in delayed response the animal with frontal lobe damage is unable to remember which foodwell was just baited. The model therefore specifies that a selective failure of retrieval follows frontal lobe damage, and this is consistent with findings reported by Weiskrantz et al. (1962) which showed that stimulation of the frontal lobe in monkeys rather surprisingly produces an impairment in the learning of simple but not of difficult tasks. That is to say, if just recent events are inaccessible, then frontal lobe animals will be expected to experience difficulty only on simple problems where learning can take place in a few trials.

While there is considerable value in models like these the variable nature of the frontal lobe deficit in man does suggest that it would be difficult for them to be used consistently in interpreting the performance of frontal lobe patients and therefore that they may not perhaps provide the most useful form of analysis.

Other studies of memory processes in frontal lobe subjects suggest a failure to make effective use of normal learning strategies, or at least only an irregular application of these, leading to the inefficient storage of information. Something of this sort is suggested by

the observations of Nicholls and Hunt (1940) who examined the performance of a single patient with partial bilateral frontal lobectomy on a variety of psychological tests. His behaviour was variable but there were many indications of a failure to approach the problem material in a way which implied the use of systematic learning strategies. For example, he did not spontaneously look for "hidden figures" in the Ishihara colour test, nor did he apparently consider the possibility that some sort of system governed the sequence of stimuli in a delayed alternation problem. Moreover, when given problems of arithmetical progression he did not discover the various appropriate strategies such as looking at numbers in alternate positions unless they were specifically pointed out, and he was unable to use them consistently when the problem became particularly demanding. However the clearest demonstration of his difficulties is provided by his extremely poor performance on the Knox cubes test. This requires the subject to reproduce the order in which a number of wooden blocks are tapped by the experimenter. The patient's performance on this test was only within the range for 7 and 8 year old children. The authors agree that this may be attributed to the fact that although he apparently numbered the blocks verbally as an aid to recall, and recalled each tap as a number, he did not make use of the strategy which is commonly adopted by normals as the sequences grow longer, that of "chunking" or grouping the numbers together.

A similar explanation is offered by Luria (1966,1973) with regard to the slow rates at which lists of words are acquired by frontal lobe patients. Luria argues that such learning impairments stem from a failure to use the technique of "part-learning" when the retention of longer lists is required. Whereas normal subjects will usually attempt to memorize a list of 10 or 12 words by learning two or three at a time, the frontal patients' performance typically shows no improvement beyond 4 or 5 items despite repeated presentations of the whole list. (Unfortunately no statistical support for these conclusions is provided.)

Barbizet's (1970) description of "frontal amnesia" also emphasizes the lack of spontaneity and flexibility of approach in patients with frontal lobe lesions. Barbizet argues for a loss of the ability to create new associations which can facilitate learning in normal subjects. The use of various unusual or idiosyncratic forms of association which may be verbal or may be based on imagery is a ubiquitous feature of organized human memory, not however apparently found in the learning processes of frontal lobe subjects.

More substantial empirical support for the possibility that frontal lobe damage disturbs the mechanisms involved in the efficient coding and organization of information in memory has been provided by a number of studies discussed by Milner (1968,1971). Milner argued that successful delayed response and delayed alternation performance depends

on the ability to keep the different trials separate so that the most recently presented stimulus is not confused with ones which have occurred previously. According to Yntema and Trask (1963), the ability to discriminate the relative recency of items in memory, particularly where these have been stored in fairly quick succession, is facilitated by a "time-tagging" process which normally operates when information is registered. Milner proposed that this mechanism is disturbed in frontal lobe patients.

Indirect support for the hypothesis has been provided by Kimura (1963) and Corkin (1964) who used a "continuous recognition" procedure to test patients with various types of cerebral lesion. In this technique subjects are presented with a series of items in succession and have to decide whether each one has appeared before in the sequence i.e. whether it is "old" or "new". It is possible, therefore, to measure the subject's tendencies to mistake new items for old (false positives), and, conversely, old items for new (false negatives). Using this procedure, Kimura (1963) presented frontal and temporal lobe subjects with a series of recurring nonsense figures. The typical picture in normals is of a rapid build up in the rate of false positives which gradually diminishes. In the case of Kimura's right temporal and frontal lobe groups, however, there was no indication of this, suggesting that such patients become more confused as the number of items in the list is increased. Comparable results were obtained by

Corkin (1964) who used a series of recurring figures which were essentially tactile versions of Kimura's stimuli. Once again there was evidence of an impairment in the frontal lobe group. On the other hand Milner (1968) failed to confirm the effect for auditory material. A series of recurring birdsongs was presented to normal patients and groups with frontal and temporal lobe lesions. The frontal lobe group were found to perform normally.

The most convincing evidence for the hypothesis that "time tagging" is disturbed by frontal lobe damage is the demonstration by Corsi (cited by Milner, 1971) that in comparison with temporal lobe patients those with frontal lesions perform badly on tests which require judgements of the relative recency of items in memory. In Corsi's experiment, subjects were presented with a series of cards with two words (or abstract designs in a separate condition) printed on each. Occasionally a test card appeared requiring the subject to indicate which of the two stimuli present had appeared more recently. In addition, because not all of the test stimuli had appeared before, a measure of the subjects' recognition could also be obtained. An analysis of the results suggested different sorts of impairment for the two lesion groups. Frontal lobe patients were significantly impaired in their judgements of recency, whereas temporals showed a significant deficit in recognition.

In view of the variability of the frontal lobe subjects' deficit on tests of memory it is not easy to be certain of the origin of the impairments which have been

found to occur. However there is evidence that an important determinant of the subjects' level of performance may be the novelty of the items which are to be retained. In Prisko's experiments, for example, deficits were found only on tasks in which the same few stimuli occurred a number of times in different combinations (clicks, flashes and colours). No deficit was found with nonsense figures each pair of which was unique. Against this interpretation no impairment was present in the tones comparisons although these stimuli also occurred more than once. Prisko did report however that very few errors were made by any group on this task, suggesting that it may have been relatively insensitive to any underlying impairment. In a comparable experiment, Stepien and Sierpinski (1960) also failed to find a deficit with tones and in their study new stimuli were used on each trial. This result also is therefore consistent with the hypothesis that where novel stimuli are presented no impairment is found in frontal lobe subjects. The deficits reported by Kimura (1963) and Corkin (1964) provide further indirect support since in these studies <u>recurring</u> stimuli were used. There is no good explanation, however, for the discrepant finding reported by Milner (1968) of the frontal lobe group's adequate performance on the recurring birdsongs task. Nevertheless the general trend of these results does suggest that the novelty of the material used is an important contributor to the frontal lobe patients' difficulties, and such findings are consistent with the "sensory disinhibition"

hypothesis. Milner (1968) in fact suggested that frontal lobe subjects might be said to suffer from an excess of "proactive interference", in the sense that they experience difficulty in suppressing or inhibiting information from previous trials.

The sensory disinhibition hypothesis makes the general prediction that novelty leads to disruption. A possible explanation of the beneficial effect of novel stimuli in some of the studies which have been discussed earlier in this section is that for the subjects they constitute situations of low interest value. The use of novel stimuli in such situations may have prevented attention's being disturbed as, for example, remaining in the dark has been shown to do.

(iii) Disturbances in the control and regulation of behaviour associated with frontal lesions

The hypothesis that response processes are disturbed by frontal lobe lesions has received attention with regard to the deficits in man as it has with animals (see p.19). For example the perseverative nature of the frontal lobe patient's behaviour has often been noted by clinicians and has also been described and discussed in great detail by Luria (1966,1968,1973), who argues that perseveration is a characteristic effect of various types of frontal damage which can manifest itself in a number of ways. Thus when

asked to draw a simple shape, patients may produce a whole series of them in rapid succession. Patients' speech may also have a similar repetitive character in severe cases. Such effects are of considerable importance for Luria's model of cerebral organization as a whole as well as his explanation of the frontal lobe deficit. In general the frontal lobes are said to have a regulatory function. They are concerned with the execution of serial forms of activity; they provide "action programs" and evaluate the outcome of completed acts in the light of the instructions which such "programs" contain. Luria views the cortex as comprising a system of zones which, although independent, in practice operate together as "working constellations" during the execution of complex psychological activities. Two complementary forms of synthetic process, each characteristic of a major cerebral area, determine and control the way in which such integrative processes operate. The first, "simultaneous synthesis", is responsible for the organization or construction of successive elements into simultaneous groups or schemata and is the "function" of the parieto-occipital region. The second, "successive synthesis", is concerned with the processing of temporally separate items, an important aspect of which involves the maintenance of the original sequential structure. This function is attributed to the fronto-temporal area. The perseverative features of the frontal lobe patients' behaviour observed by Luria and the way in which serial forms of activity are disturbed are

consistent with this view of cerebral organization. For instance lesions of the premotor or superior postfrontal cortical regions cause disturbances in the organization of limb movements; speech is impaired by lesions of the inferior divisions of the left frontal lobe. Visual search and scanning processes may also be disrupted, and while the frontal lobe patient may be able to recount a story coherently he cannot give an outline of it by extracting a skeleton plan of "ideational relationships" (Luria and Tzvetkova, 1958) There is also a tendency for skills and other well established sequentially organized forms of behaviour to deteriorate as if the usual mechanisms of contraction and "telescoping" in time have been interfered with. These disturbances often take the form of sequences of perseverative responses.

An experiment reported by Milner (1964) also provides support for the view that perseveration is an important effect of frontal lobe lesions in man. In this study patients with various types of cerebral lesion were required to sort into four piles cards on which certain figures appeared. The number of figures used and their form and colour were varied so that there were three possible ways of classifying the material. One of these was selected by the experimenter and the subject was informed whether he was "right" or "wrong" as each card was sorted. After each block of ten consecutive correct responses the basis for sorting was changed, forcing the subject to abandon his

present strategy in favour of the new correct one. The main finding of interest was the poor performance of the dorsolateral frontal lobe groups in contrast to those patients with orbito-frontal, temporal and posterior cortical damage. This result may be compared with many from the animal experiments discussed in Chapter One which suggest a special relationship between perseveration and orbital rather than dorsolateral damage. The difficulties which the dorsolateral group experienced on this task appear to arise almost exclusively from a failure to shift the basis of sorting as required, suggesting the perseveration of a (now) incorrect principle. These results however do not match those of Teuber et al. (1951) who carried out a comparable investigation with patients with gunshot wounds. There was no evidence in this experiment of higher error scores in frontal lobe patients compared with any other groups. There were certain procedural differences however between the two studies which may have been partly responsible for this discrepancy, which if nothing else at least confirms the general impression that the frontal lobe deficit in man is both variable and elusive.

One of the most important ways in which the regulation of behaviour is achieved is via the use of language. According to Luria one of the effects of frontal lobe damage is to disturb this process giving rise to an aspect of the frontal lobe deficit which has often been commented on by clinicians and which was characterized

by Teuber (1964) as "a curious dissociation between knowing and doing". That is to say, the patient appears to understand instructions but is unable to behave in accordance with them. He can even repeat them but he cannot use them as a guide to action. The deficit has been shown to be present in a variety of different situations. Milner (1964) for example reported the results of a maze learning experiment in which the subject had to learn the correct path between two points on a board composed of parallel rows of nailheads, using a stylus to tap out the sequence of moves. Any deviations from the correct path were scored as errors and were accompanied by a loud click from the error counter. A most significant finding was the persistent failure of subjects with frontal lobe lesions to comply with the "rules of the game". For instance although the instructions specified that diagonal moves between nailheads were not permitted, frontal lobe patients nevertheless continued to make them. They seemed not only insensitive to error but also unable to be guided by the test instructions. These observations are not substantiated however by those of Newcombe (1969) who found no evidence for a maze learning deficit in her frontal lobe group.

McFie and Thompson (1972) compared the performance of patients with frontal, temporal and parietal lobe damage on the Wechsler Picture Arrangement test. This requires the

subject to arrange a number of pictures in sequence so as to tell a particular story. Subjects with right frontal lobe lesions were significantly more likely than the nonfrontal groups to leave the pictures in the order presented by the experimenter (although their overall performance was not significantly worse). That is, they appeared to understand the rule - that the order of the pictures is supposed to tell a story - but could not apply it correctly. They neither appreciated that the illogicality of the "stories" they offered was inconsistent with the aims of the task, nor could they modify their behaviour in the light of the implied instruction to move the pictures around.

Like Luria, Pribram (1960) has also argued that the frontal lobes are concerned with the control and regulation of sequentially organized activities. He proposed that the frontal lobes ("frontal intrinsic systems") act as the association cortex for the limbic system and may be thought of as the locus of the hierarchically organized "plans" (discussed by Miller et al., 1960) which guide behaviour. As Miller et al. (1960) proposed, plans are composed of "TOTE" units i.e. sequences of instructions, including procedures for executing responses and procedures for evaluating their outcomes. The whole process of evaluation is governed by feedback mechanisms, and when one TOTE unit is completed i.e. when there is a match between the desired situation and the existing one, the "flow of control" passes

on to the next. Lesions of the frontal lobe can therefore be expected to interfere with complex sequences of behaviour involving the concatenation of such TOTE units; the evaluation process will be disrupted and the structure and pattern of planned behaviour disturbed, resulting in what is described as a deficit in "intentional behaviour".

Various experiments discussed by Luria (1966,1973) also suggest a dissociation between what the frontal lobe patient knows he should do, and what he actually does. Thus when asked to carry out a simple movement such as raising a hand, Luria reports that in severe cases the patients will continue to repeat the instruction even when they have ceased to perform the required action. Or, when asked to raise a hand which is under the bedclothes, the instruction may be repeated but the movement not carried out at all. Such observations lack experimental control but the hypothesis does receive support from a number of more systematic physiological studies discussed by Luria and Homskaya (1964) and Luria (1973). These investigations suggest that patients with frontal lobe lesions may be reliably differentiated from those with lesions located more posteriorly on the basis of indices such as G.S.R., E.E.G. and evoked potentials. When specific changes in these are monitored under various experimental conditions, they not only appear to be sluggish or undifferentiated in frontal lobe patients when attention to individual stimuli is

required, but also fail to show the enhancement found in other patients, when additional instructions - such as to count the number of signals - are given. These findings lend support to the idea that the mechanisms by which language controls behaviour are disturbed by frontal lobe injury.

(iv) Disturbances of perception associated with frontal lesions

Disturbances of sensation and perception are not usually thought to form part of the frontal lobe syndrome. However Teuber (1964; Teuber et al., 1949) has found a very small but reliable deficit in visual search in patients with gunshot wounds affecting the frontal cortex. The task used by Teuber involved the presentation of an array of patterns which were displayed irregularly on a large screen. One of these figures was duplicated at the centre of the display, and the subjects were required to search the surrounding field for the figure indicated. Both accuracy and speed of search were found to be selectively impaired in the frontal lobe group compared with cases of posterior cortical damage and normal controls. In view of the possibility that damage has occurred to the "frontal eye-fields" (Latto and Cowey, 1971a,b) it is possible that defective eye movements may be partly responsible for this poor performance. In fact Luria (1966,1973) describes cases in which the pattern of eye movements in patients with

extensive frontal damage is grossly disturbed during the inspection of complex visual displays such as paintings.

Teuber also found frontal lobe patients to perform worse than other groups on a modified Aubert task and on a task of "personal orientation". In the former, subjects had to set a line to the vertical under conditions of body tilt. Compared with the posterior group the frontal lobe group showed a significant degree of overestimation. In the second task the patients were shown two diagrams of the human body, one facing away from them and one facing towards them. Numbers were drawn at various points on these diagrams and the subject was required to touch the relevant points on his own body in the order indicated by the numbers. The performance of the frontal lobe group was defective relative to that of the right posterior group, but not the left.

In his interpretation of these results Teuber argued that the three tasks involved should be thought of as "sensori-motor" in the sense that they are neither completely sensory nor completely motor. His explanation of the frontal lobe group's performance was in terms of a disturbance in "corollary discharge", a hypothetical mechanism which presets the sensory (posterior) regions of the brain at the instigation of a voluntary movement, thus preparing the sensory systems for the changes which are expected to result from the execution of the intended movement. This mechanism is apparently comparable to that described by Held

(1961) and others, and it is also reminiscent of Denny-Brown's suggestion (1951) that the basis of the frontal lobe deficit is a failure to "visualize consequences".

In a test of Teuber's hypothesis, Welch and Goldstein (1972) investigated the ability of brain damaged and control subjects to adapt to visual displacement produced by prisms worn over the eyes. The argument is presumably that successful adaptation would require the integrity of the corollary discharge mechanism. One measure of adaptation was taken to be the degree of "negative after-effect" - the extent to which the subject continues to compensate for the displacement when the prism has been removed. According to this measure the brain damaged group as a whole showed less adaptation than the controls. Contrary to Teuber's hypothesis however frontal lobe patients showed significantly greater negative after-effects than the nonfrontal group, which probably implies a more successful level of adaptation to the displacement (unless, of course, they over-adapted: this does not appear to have been the case).

This review of the effects of frontal damage in man suggests that the frontal lobe deficit consists of a recognizable, although ill defined set of disorders. Moreover the disorders which have been observed cannot be elicited with any great degree of reliability, and they often seem to depend on the exact conditions of testing. The choice of a theoretical framework within which they might be

integrated will depend on which of them are thought to be direct expressions of the dysfunction of some hypothetical mechanism, and which are regarded merely as secondary phenomena which result only indirectly from a disturbance of this mechanism. To take an example, suppose that reading is seen to be impaired following a certain form of cerebral lesion. The conclusion that this necessarily reflects an underlying linguistic disorder may be unjustified since the deficit may really be due to deranged eye movements or some other factor. The basic irregularity of the frontal lobe deficit makes it difficult to decide upon the most useful way of analyzing the various impairments which have been discussed in this chapter. In the next chapter however, it will be suggested that the various memory and other deficits which have been reported to follow frontal lobe damage do not reflect simple disturbances in the storage and retrieval of information and are perhaps more usefully considered as symptomatic of an impairment of other mechanisms.

The mechanisms in question are those envisaged by the "sensory disinhibition" hypothesis which will now be presented in some detail and discussed in relation to the various features of the deficits in man.

Chapter Three

The Sensory Disinhibition Hypothesis

(a) The Hypothesis

The explanation of the frontal lobe deficits in terms of a breakdown in the mechanisms by which the central nervous system controls or inhibits afferent stimulation is not new. It is implicit in the work of Stanley and Jaynes (1949) and Brutkowski (1964). A formal statement of the "sensory disinhibition" hypothesis however has been provided by Buffery (1964), and since the experiments to be described later derive from it, it is reproduced below in full.

" (i) Lesions in the lateral surface of the frontal lobes interfere with the physiological mechanisms underlying sensory inhibition.

(ii) Because of an excessive bombardment by the disinhibited sensory input the frontal animal has great difficulty in selectively attending to specific stimuli.

(iii) Where the registration of specific stimuli is necessary for the establishment of a specific behaviour pattern the frontal animal will show an impaired performance.

(iv) The delayed response task is particularly sensitive to this impairment as its solution requires

(a) the registration of a specific cue for each problem

(b) the storage of a particular cue by a central mediational process (e.g. memory trace)

(c) the retrieval of the particular cue as exhibited by its selection from a number of alternatives.

(v) A disinhibited sensory input could interfere with each stage of the delayed response task by:

(a) distracting the animal with irrelevant stimuli during registration

(b) interfering with the animal's central mediational cues during storage (e.g. disrupting the memory trace or accelerating its rate of decay)

(c) confusing the animal with irrelevant alternative stimuli during retrieval.

(vi) If the critical stimuli of a task are made more distinctive, and/or the extraneous stimuli kept at a minimum, either by physical modification of the environment or physiological manipulation of the animal, then the frontal animal's performance may be improved."

If the effect of frontal lobe damage is to produce a condition of sensory disinhibition in the animal then the sort of impairment which is envisaged is presumably one in which there is a "widening" of attention resulting in a tendency for stimuli especially if novel which would not

normally receive attention to be detected and processed. This may be contrasted with the view taken by e.g. Costello (1956) and Butler and Eayrs (1969) who characterize the attention impairment as one which involves a narrowing or reduction in the capacity for processing information. Butler and Eayrs (1969) tested monkeys with frontal lesions on the "conditional reaction", a two choice visual discrimination task in which the two relevant cues are presented against a variable coloured background. A change in this background signals a reversal of reinforcement from one cue to the other. The performance of dorsolateral animals was found to be deficient on this problem compared with animals which had received orbital lesions. Butler and Eayrs proposed that this impairment arose from an inability to attend to two separate channels of information, i.e. information concerning the position of the reinforced cue and information about the nature of the background. In similar vein Costello (1956) found that frontal lobe patients could process information about either the position or type of figures appearing on a card but experienced difficulty, compared with controls, when required to do both.

These two interpretations of the effects of dorsolateral frontal lesions on the animal's attention processes may perhaps be usefully contrasted by viewing the sensory disinhibition hypothesis as a hypothesis concerned with a disturbance in the ability to select, while the Butler and

Bayrs hypothesis emphasizes an impairment in the ability to divide attention. The two hypotheses are therefore not inconsistent with each other. In fact it may be that sensory disinhibition actually produces the difficulty in attending to two separate channels by allowing the animal to become distracted so that important changes in the relevant channels are not detected quickly enough.

(b) The sensory disinhibition hypothesis in relation to the effects of frontal lobe damage in man

In view of the variable nature of the frontal lobe syndrome, and the frequent discrepancies in the various reported studies of frontal patients discussed in Chapter Two, it is possible that the sensory disinhibition hypothesis could provide the basis for interpreting at least some of the features of the frontal lobe deficit. That is to say, it may be more useful (and parsimonious) to think of the memory impairments, the failure to use conventional strategies of learning, the inability to follow instructions and the disturbances of response processes as arising from the difficulty which the patient has in maintaining attention to the relevant cues, owing to sensory disinhibition. In fact disturbances of attention in frontal lobe patients have been described in great detail by Luria (1966,1973). Unfortunately these observations are usually of small numbers of patients and are difficult to interpret because appropriate comparison groups are lacking. However Luria

(1973) concluded that the frontal lobes "participate decisively in the higher forms of attention". Disturbances of attention are also thought to be important by Pribram (1967,1969). Spinelli and Pribram (1967) found that the recovery cycles of cells in the visual system (of monkeys) could be altered by electrical stimulation of the frontal cortex. Pribram (1969) suggested that this efferent inhibitory process provides a mechanism by which input to the cortex could be controlled or "parsed". By "parsing" Pribram seems to mean the process of grouping appropriate items together so that overall temporal organization of the input is achieved. It may be comparable to the process of "segmentation" envisaged by Neisser (1967) as one of the most important mechanisms of selective attention.

The fact that the novelty of the material used in memory tasks is an important factor in the frontal lobe patient's performance has already been described as consistent with the sensory disinhibition hypothesis. Additional support for this is provided by Poppen, Pribram and Robinson (1965) who studied a group of lobotomized schizophrenics and a group of normal controls on a multiple-choice visual discrimination learning problem. The task was modelled on the procedure used by Pribram (1961) with monkeys and involved the variation of the number and novelty of the alternatives. Reinforcement was attached on a systematic schedule to a number of designs such that both novel and familiar cues were eventually

rewarded at one time or another. The results paralleled those found with monkeys in the sense that the lobotomized subjects changed promptly to the correct cue only when it was novel. There was no control lesion group in this study however and one would also have to take into account the special psychiatric status of the sample in interpreting these results.

(c) The physiological evidence for a mechanism of sensory inhibition

The explanatory value and other merits of the sensory disinhibition hypothesis have now been discussed in some detail and it remains therefore to examine briefly the evidence for a "frontal lobe system" which might provide the physiological basis for the mechanism of sensory inhibition. This has been described in full by Buffery (1964) and will be presented here only in condensed form.

The concept of a mechanism by which the central nervous system can control its own input and level of arousal can be traced to Eusebius Valli (1793) and received support from the early studies of Head and Holmes (1912). They demonstrated the existence of corticothalamic pathways which have subsequently been shown to have both facilitatory and inhibitory effects on synaptic transmission in the somatosensory relay nuclei. It seems also that modification of sensory input, both inhibitory and facilitatory, can be achieved by way of two mechanisms: (1) the diffuse

thalamocortical projection system in its interaction with the specific thalamocortical projection system; (2) the reticular activating system. The evidence for central control of afferent stimulation was extended by the work of Hernandez-Peon (1955) and Livingston (1959) who concluded that modification of sensory evoked responses was possible by way of the reticular activating system. The effect may be either inhibitory or facilitatory. The work of Hernandez-Peon however has been extensively criticised by, for example, Worden (1966) and its conclusions are now widely believed to be incorrect.

Buffery (1964) also discussed the possibility that these mechanisms are disturbed by damage to a "frontal lobe system" which mediates the physiological events involved in sensory inhibition. He suggests that critical pathways in this system link the dorsolateral frontal lobe with the reticular activating system via the caudate nucleus, hippocampus and subthalamus and reviews anatomical and electrophysiological evidence for such links. Taken together, the studies cited by Buffery appear to constitute firm support for a "frontal lobe system" which could provide the physiological foundation for sensory inhibition. Damage to the system would, on this hypothesis, cause alterations in the subjects' responsiveness to external stimuli because of interference to corticothalamic pathways.

Chapter Four

The Main Study

Introduction

The aims of the first series of investigations were as follows:

(a) To develop a discrimination learning situation suitable for human subjects, based on the one used by Buffery (1964, 1967) with baboons, and to administer this to three groups of selected neurosurgical subjects: those with frontal lobe lesions, those with temporal lesions, and those with lesions of the peripheral nervous system.

(b) To explore the applicability of the sensory disinhibition hypothesis in relation to the process of visual search in human subjects.

(c) To explore the applicability of the sensory disinhibition hypothesis in a classification task using human subjects.

Method

Subjects

The two groups of brain-damaged patients were selected from the neurosurgical records of the London Hospital, Whitechapel and Old Church Hospital, Romford, Essex. In most cases they had undergone surgery for the removal of intracranial tumours of various kinds during the previous ten years. As such, they were all outpatients who attended the Outpatients' Clinic once or twice a year. The majority were taking varying dosages of anticonvulsant drugs such as Epanutin. No patient was tested until at least six months had elapsed since operation. In fact some

of the experiments were carried out on two patients in their early post-operative stages, i.e. within ten days of surgery. It was clear however that the tasks were too demanding and not suitable for administering in a hospital ward. Data obtained from these patients are not presented here. With the assistance of the consultant neurosurgeon, Mr. Tom King, suitable subjects were selected on the basis of radiographic and other diagnostic and clinical evidence. Suitable cases were considered to be those

(i) who were under the age of 65,

(ii) who had little or no clinically obvious linguistic, visual or motor impairments,

(iii) who had sustained lesions of either the frontal or temporal lobes which could be localised anatomically with reasonable certainty,

(iv) who it was thought would be willing to cooperate in the proposed testing sessions at the hospital.

Patients with a long history of epilepsy were avoided as far as possible.

The number of potential subjects was very small, particularly where the temporal lobe group was concerned, and, while every effort was made to equate the two groups in all respects, since no real opportunity for choice arose, there was no attempt to match pairs of patients in the two groups.

The control group was composed of patients who had received laminectomies during the treatment of prolapsed intervertebral discs. These were curiously unwilling to attend the hospital, possibly because of work pressure, and the majority were therefore tested in their own homes, unlike the brain lesion groups. Details of the composition of the two groups are summarized in Table 1.

All subjects in the brain lesion groups were right handed with the exception of one temporal lobe case. Full details of the patients are to be found in Appendix A. Intelligence Quotients are known for some of these patients but are not presented here. Reconstructions of the locus and extent of the brain lesions were provided by the neurosurgeon and are presented in Appendix B. It may be noted that in most cases these lesions are considerably less radical than those sustained by subjects in the studies of, for example, Milner (1964, 1968, 1971).

The experiments which were carried out are described in more detail below.

Experiment 1. Discrimination Learning

Introduction

This experiment consisted of modified versions of two of the discrimination problems employed by Buffery (1964) - Tasks 2 and 3 (see page 31). Both of these involve the systematic variation of the number and novelty of the incorrect alternatives in a multiple choice visual discrimination task. The sensory disinhibition hypothesis would

Table 1. Summarized details of the groups of patients

Group	Frontal (F1-10)	Temporal (T1-10)	Control (C1-10)
N =	10	10	10
Average age	51y.3m.	44y.	42y.
Average length of time since surgery	4y.1m.	4y.10m.	4y.0m.

(Full details may be found in Appendix A)

presumably predict poorer performance in frontals on any conventional discrimination learning problem providing that the correct stimulus is not novel, since the restriction of attention to one stimulus is required. The most potent determinant of attention however is said to be the novelty of the irrelevant alternatives. Hence a simple increase in the number of alternatives with novelty minimised would be expected to have little effect on the performance of frontals compared with temporals and controls. On the other hand, due to the greater distraction effects present, frontal lobe patients should experience particular difficulty compared with temporals and controls where novelty is at a maximum.

Buffery used small plastic toys as stimuli but in this experiment it was decided to use more abstract stimuli differing from each other in certain specified ways (see below).

Design

In Task 1 (Buffery's Task 3) a fresh set of incorrect discriminanda was introduced each time the subject reached criterion. In addition the number of discriminanda was increased by two. Schematically this may be represented as follows:

	Stimuli	
	Correct	Incorrect
Stage 1	A	B
2	A	C D E
3 etc	A	F G H I J

The rewarded stimulus (A) remained the same throughout the whole task.

In Task 2 (Buffery's Task 2) the number of stimuli was increased whenever the subject reached criterion, as before, but only two new ones were added each time to the discriminanda already present. Schematically:

	Stimuli	
	Correct	Incorrect
Stage 1	A'	B'
2	A'	B' C' D'
3 etc	A'	B' C' D' E' F'

Again the rewarded stimulus (A') remained the same.

A criterion of two consecutive correct responses was used in both tasks. The order in which the two tasks were presented was alternated for each subject. Subjects were individually tested.

Materials

In both tasks the stimuli were pieces of white card ($2\frac{1}{2}$" x 2") bearing a coloured shape at each corner. There were 12 possible shapes, e.g. circles, hearts, squares, triangles, and all cards were made up of a combination of these. No shape appeared more than once on the same card. In Task 1 the shapes were all green, while in Task 2 they were all red. (See Figure 2.)

The series of cards were constructed so that each card differed from its immediate neighbour in respect of one shape only, chosen randomly. The first card of the series was designated the positive or correct discriminandum i.e. the one which was to be subsequently reinforced. The positive discriminanda were the same for all subjects.

A board measuring 15" x 12" was used for presentation of the material. It was divided into 12 spaces next to each of which was printed the appropriate number from 1 to 12 (see Figure 3).

Procedure

Although reference was made to a standard set of instructions in this and all other experiments, due to differences in the subjects' level of anxiety, intellectual ability and attitude towards the tests, there was some variation in how the various tasks were explained. The subject was seated in front of the board described and was told that the experiment was a kind of game in which the

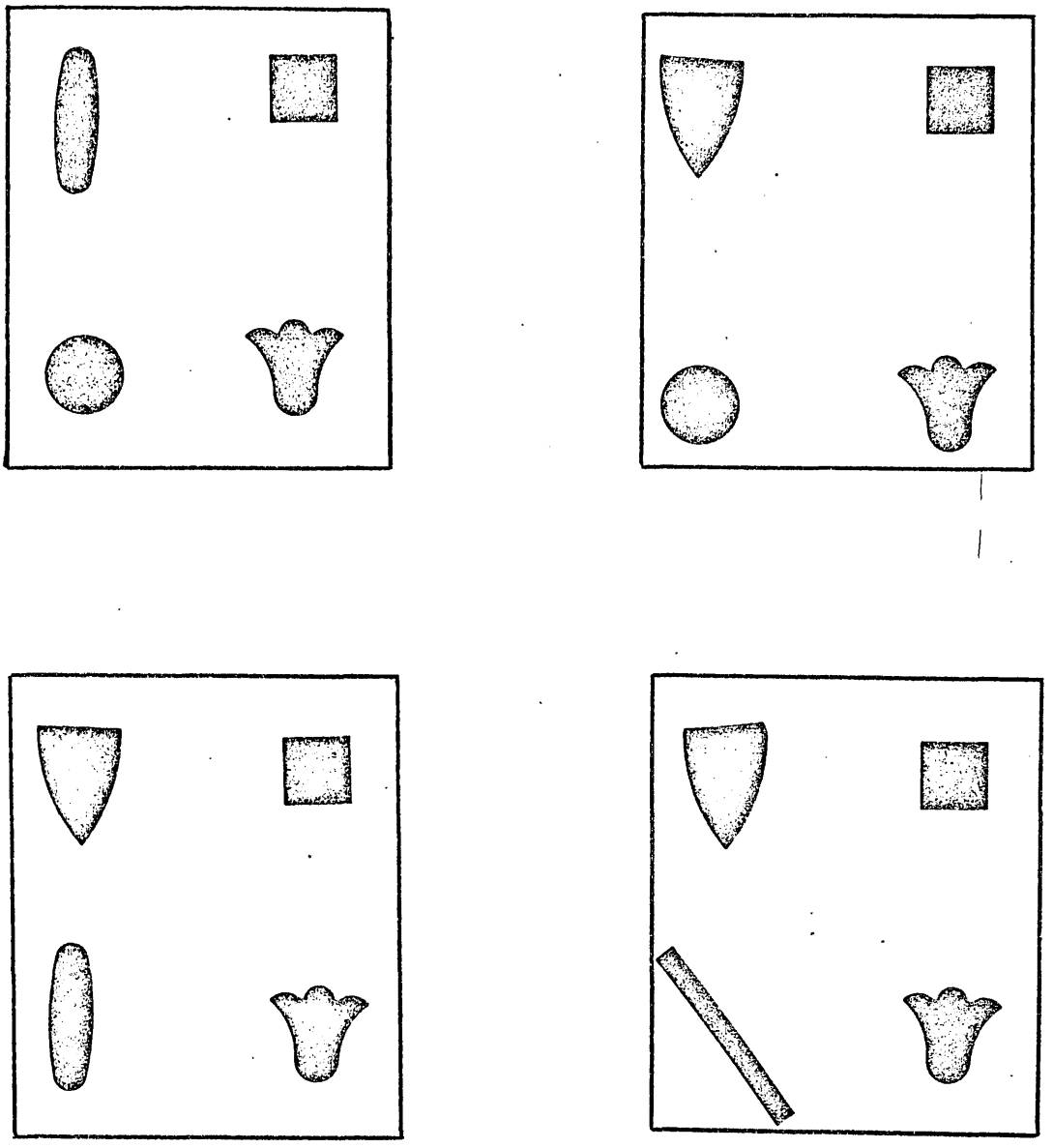

Figure 2. Part of the series of cards used in Experiment 1 (Discrimination Learning)

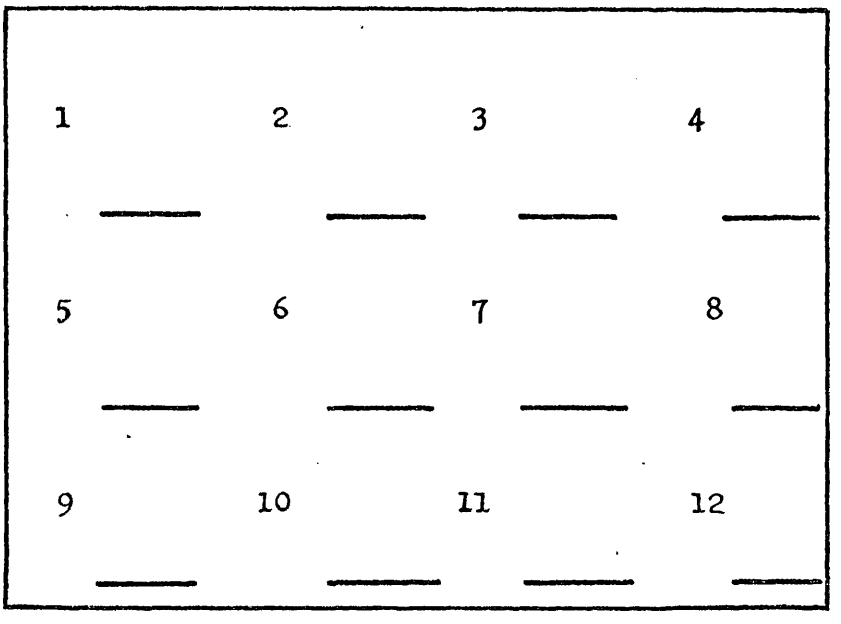

Figure 3. Design of the board used in Experiment 1 (Discrimination learning)

object was for him to win as many plastic counters as possible. He was told that small cards would be placed on the board and that he should choose one of these by giving the experimenter the number immediately next to it. He was also told that whether or not he won one of the plastic counters depended on which card he chose, and that the number of the space in which the card appeared had nothing to do with his success or failure. (The spaces were numbered to enable the subject to indicate which card had been selected, to avoid any confusion.) He was again reminded that it was his job to win as many of the plastic counters as he could.

Having ascertained that the subject understood the general idea, the first two cards (e.g. A and B) were placed on the board, the position of card A being chosen according to a prearranged random schedule. The subject was asked to make his choice and having done so received "reinforcement" if he chose card A. Regardless of whether he was given a plastic counter, the two cards were then taken from the board, "shuffled", out of the subject's view and replaced at different positions on the board. This procedure was repeated until the subject chose card A twice in succession, when the discriminanda were taken away once again. In the case of Task 1 the incorrect discriminandum (card B) was then removed and replaced by three new ones (C D E). In Task 2 A' and B' remained, and C' and D' were added to the board. The procedure then continued as before until the subject achieved criterion once again. Additional

material was then added as before up to a maximum of 10 shapes. Each time any change was made all cards were removed from the board.

A note of the subject's choices was made and the experiment terminated either when criterion had been reached with 10 discriminanda present or when the subject had made thirty choices. No time limit was imposed, a fact subsequently much regretted by the experimenter on account of the reluctance of some subjects to reach a decision until weighty consideration had been given to all the choices available and the merits of each pondered at length.

Experiment 2. Visual search

Introduction

The experiments described in this section were suggested by Neisser's (1963) extensive investigations of search processes in normal subjects. In these studies the subjects were required to scan lists of letters for certain specified target letters as quickly as possible.

As mentioned previously, Teuber (1964) reported generally slower search times in frontal lobe patients compared with a control group and with a number of subjects with posterior cortical lesions. According to the sensory disinhibition hypothesis, however, an important factor determining performance in frontals should be the variability of the "background" material (or "negative set") through which the search is made. Rabbitt (1967) has reported that

this is not a particularly important determinant of search time in normals, although Gordon et al. (1971) have found increases in search time in a letter cancellation task with increases in irrelevant item variety, particularly up to where nine or 12 irrelevant letters are present. Where a relatively small number of different stimuli is used, distraction effects should be minimal and the performance of frontals little affected compared with temporals and controls. As the variability of the negative set is increased however, by increasing the number of different stimuli employed, the performance of the frontal lobe group should be disproportionately impaired compared with temporals and controls.

Since the number of targets for which search is conducted has generally been found to be an important determinant of search time in normals, this variable was also included in the present experiment. A study of particular relevance was reported by Rabbitt (1964), who showed that the time required to ignore a symbol as irrelevant in scanning a visual display is dependent on the number of items (targets) which the subjects are asked to look for. As Rabbitt argues, if deciding whether or not a particular item is irrelevant involves "testing" for the presence of specific features (e.g. angularity, location of horizontals), then this result is consistent with the view that subjects have to carry out a wider range of tests on the items in the display as the number of targets specified increases. Presumably, this means that, with an

increase in the number of targets, there will be a greater opportunity for distraction from the irrelevant items since more "analysis" of these will be required. According to the sensory disinhibition hypothesis, therefore, increasing the number of targets will produce a disproportionate increase in search times in frontals compared with temporals and controls. It is arguable that, were novel targets to be used, this prediction would not necessarily hold. However, familiar stimuli such as letters and numbers would not seem to come into this category.

A further prediction about speed of search in frontals may be derived from a study by Costello (1956) which investigated the ability of patients with prefrontal leucotomies to identify, and also to indicate the position of, certain meaningless figures presented in a visual display. Briefly, it was found that subjects were unaffected when required to identify the figures or to locate them spatially, but experienced considerable difficulty when asked to perform both operations simultaneously. This suggests that there is an inability to process two different kinds of information at the same time and leads to the prediction that frontals should be relatively more severely impaired when required to search for two different types of target rather than two targets of the same type. This might be explicitly linked to the sensory disinhibition hypothesis, and the arguments derived from Rabbit's experiment discussed above, in the sense that

subjects are presumably exposed to a greater variety of stimuli and must also make more "tests" in the "two different types of target" situation. The opportunity for distraction from the background therefore will be greater compared with the "two targets of the same type" condition.

Design

Two main variables were investigated in the present experiment:

(i) the size of the positive set i.e. the number of targets specified by the experimenter. The subject was required to look simultaneously for 1, 2 or 4 targets;

(ii) the size of the negative set - more specifically the size of the population from which the background or irrelevant "non target" material is drawn. The population sizes used in this study were 4, 14 and 25.

The effect of two types of stimulus, i.e. letters and numbers, was also investigated. The subject was required to search simultaneously through a list of letters and numbers for a specified letter and number.

Overall therefore there were six different conditions in which visual search was studied:

	Positive Set (or Target) Size	Negative Set Size	Stimuli
Condition 1.	1	4	Letters
2.	1	14	"
3.	1	25	"
4.	2	24	"
5.	4	22	"
6.	2	25 (letters) 9 (numbers)	Letters and Numbers

The order in which these conditions were presented was randomised for each subject.

Materials (see Figure 4)

Lists of appropriately selected letters were drawn up within the constraints mentioned above, and were printed in upper case type in 25 rows of six letters each on plain white cards measuring 8" x 5". Three cards were designed for each experimental condition making 18 in all. The target appeared on one line only and its position within the line was balanced across conditions. To avoid anticipation the position of the line in which the target letter appeared was varied within each condition so that there was an equal probability of its appearing near the beginning, in the middle, or toward the end of the list. Where search for more than one target was required only one of the letters actually appeared in the list. In the case of the "letter and number" condition the lists were composed of rows of letters and numbers mixed together and selected at random.

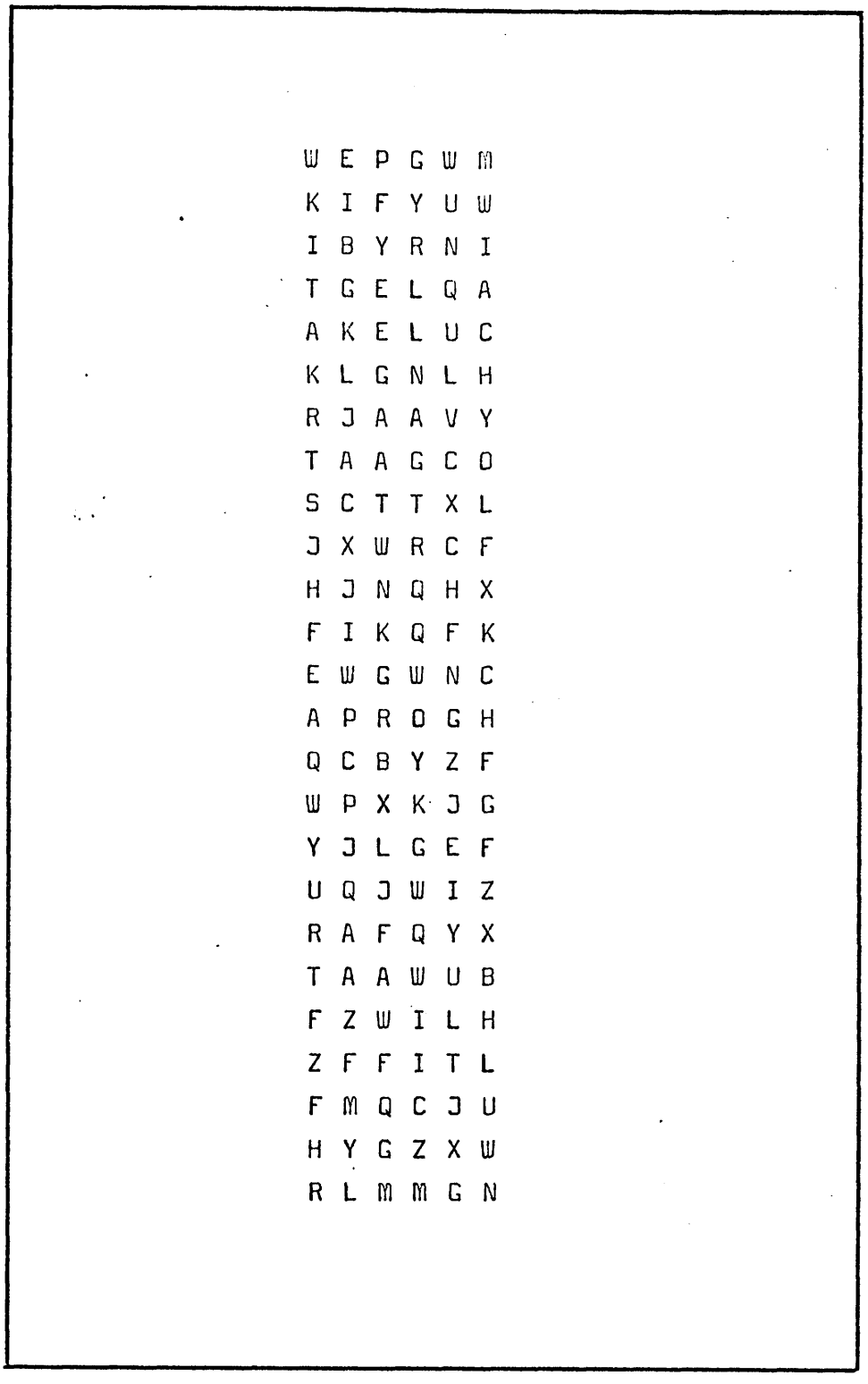

Figure 4. One of the lists of letters used in Experiment 2 (Visual Search)

Smaller cards showing just the target letters themselves were also prepared and the position of the target as shown on these with more than one item was also systematically varied.

Procedure

The material was presented to the subject in blocks, each block consisting of the set of three cards for any particular condition. The order of the cards within each block and the order in which the blocks were presented was arranged separately for each subject according to a random schedule.

The subject was first of all shown a sample list and told that he would be required to look through similar lists to find particular letters presented on a different card. He was told to scan as quickly as possible down the list starting at the top, and to keep looking for the letter specified until he either found it, or was asked to stop looking.

It was also suggested to him that the task might be more difficult than it appeared, but he was reassured that there were no "trick" cards, i.e. no cards on which the target did not appear somewhere. (Despite this, the initial reaction of a number of subjects to failure was to thrust the card away with an air of finality, convinced that they had been misled.)

The subject was told that he would be timed and was also requested to leave the card on the table in front of him until he had finished. No practice trials were provided. The time required to find the target was recorded using a stopwatch and whenever three minutes of unsuccessful search had elapsed the subject was stopped, the position of the target pointed out, and the next card presented. In fact the percentage of failures turned out to be very small (2%).

Experiment 3. Classification

Introduction

This experiment set out to investigate selective attention in a card sorting task. The prediction of the sensory disinhibition hypothesis is that sorting times in the frontal lobe group will be increased compared with temporals and controls where novel distracting material is present but relatively unaffected where there is a simple increase in the amount of irrelevant information with novelty held at a minimum.

If the position of the feature relevant to the sorting task is constantly varied, the subject presumably samples more of the surrounding irrelevant material while trying to locate it. There will be a greater opportunity for distraction under such conditions and the sensory disinhibition hypothesis therefore predicts increased sorting times for the frontal compared with the temporal lobe and control groups. The variables under investigation

therefore were:

(i) The amount of irrelevant information presented to the subject on the cards. Either two or eight irrelevant features were used.

(ii) The novelty of this information. The irrelevant features were either all the same as or all different from each other.

(iii) The position of the relevant feature. The position of the "target" figure either varied randomly or was fixed in one particular place.

The first two of these were suggested by the experiments of Buffery referred to previously.

The design of this experiment was therefore a three way factorial set out below:

(i)	Number of irrelevant features	2	8
(ii)	Novelty of irrelevant features	All same	All different
(iii)	Position of relevant features	Fixed	Variable

Materials (see Figure 5)

Plain white cards measuring 2" x $3\frac{1}{2}$" were used in this experiment. Four target shapes of the same colour were selected from a pool of 16 shapes. There were five possible colours (red, blue, green, yellow and brown).

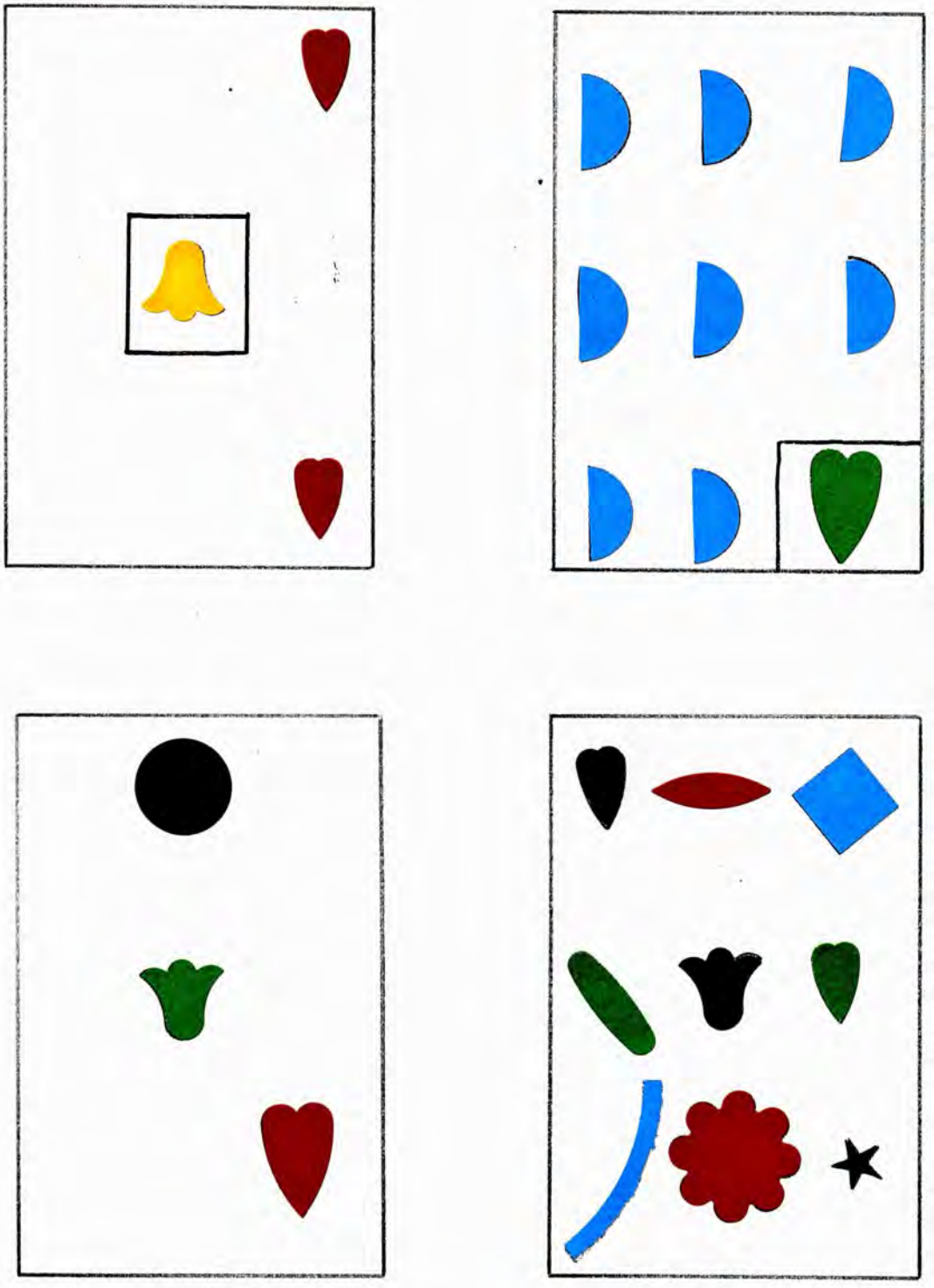

Figure 5. Examples of cards from four of the packs used in Experiment 3 (Classification)

In packs for the fixed target conditions these shapes were displayed on the cards in the same position throughout the whole pack while in the variable target condition the position of the target was varied randomly. Each card was divided into nine imaginary parts one of which was selected at random for the position of the fixed targets. Each target shape in these conditions was presented within a square outlined in black ink. Either two or all of the remaining positions were then filled with the irrelevant material. In the case of the non-novel conditions, only one shape, always of the same colour within a pack, was selected and this appeared either in all eight, or in two randomly selected positions. In the novel conditions, irrelevant material was selected at random from the whole pool of shapes and colours with the exception of course of the relevant target figures.

Each of the four target shapes appeared eight times in a pack making the total number of cards 32. In addition the target shapes were displayed alone on separate cards to indicate the four separate sorting piles. Two shorter practice packs of 16 cards each were also prepared. The order in which the eight packs were presented was randomized for each subject.

Procedure

Each pack of cards was shuffled and presented to the subject with the instruction to sort them into the four piles indicated by the shapes appearing on the four cards

arranged in front of him. In the case of the fixed target conditions, the subject was told that only shapes within the black square were relevant. He was encouraged to work as quickly as possible but to avoid errors of sorting as far as possible. Before starting on the first of the experimental packs the subject was given the two practice packs for sorting.

The subject was also told that he would be timed and his sorting times were recorded using a stopwatch.

Further remarks

All subjects were invited by letter to attend a testing session at the hospital by appointment. The response on the whole was rather disappointing as only about a third of those who were approached were willing to participate. No mention of travelling expenses had been made but it is not clear whether the generally poor response was partly due to this. Subjects tested more recently, in particular all control subjects, were offered travelling expenses but as it turned out most of these preferred to be tested in their homes during the evening.

The conditions of testing often left a lot to be desired and ranged from those requiring administration of the tests across a theatre trolley to those where testing had to be carried out in an internal room measuring $4\frac{1}{2}$ by 5 feet, with no ventilation. There were comparable

problems when patients preferred to be seen at home rather than the hospital. Although privacy and reasonably quiet surroundings were requested in advance, there was, on occasion, some fairly fierce competition from television sets and the odd spectator. Children could usually be prevailed upon to make themselves scarce, but curious and understandably anxious spouses were more difficult. The other main problem was of sometimes having to conduct the experiments on coffee tables of minute proportions. Fortunately no bedside testing was required.

On average the whole testing session lasted just under one hour.

Although there were some variations the basic structure of each testing session was as follows:

Card sorting	(Two Packs)
Discrimination learning	(Task One or Two)
Visual search	(Three conditions)
Card sorting	(Two Packs)
Visual search	(Three conditions)
Card sorting	(Two Packs)
Discrimination learning	(Task One or Two)
Card sorting	(Two Packs)

Results

Experiment 1. Discrimination Learning

There were wide individual differences in the results of this experiment. Some subjects, even those with brain damage, appeared to find the tasks extremely straightforward while others showed little or no insight after 30 often laborious trials. A preliminary survey of the results as a whole suggests that little was to be gained from examining the effect of increasing the number of discriminanda from two to ten. Any group trends appear to be swamped by intersubject variation. In Table 2 the total number of trials to criterion for all subjects is presented for each task. The minimum possible score is 10, the maximum 30.

A Two Way Nested Analysis of Variance (3 x 2) was carried out on these scores, the results of which are summarized in Appendix C. Control group scores as a whole differ from those of the frontals and temporals ($F = 6.34$, $p < 0.001$, one tailed test), but as inspection of the figures would suggest, there were no significant differences among the brain lesioned groups ($F < 1$). So although brain damage does appear to have produced a learning deficit, there are no selective effects due to locus of lesion. Frontal and temporal lobe patients learn the discriminations with equal (lack of) facility. The prediction that frontals should find Task 1 disproportionately more difficult than Task 2 compared with temporals and controls therefore was not borne out.

Table 2. Total number of trials to criterion (Maximum 30) in Experiment 1. (Discrimination Learning)

FRONTALS			TEMPORALS			CONTROLS		
Subject Number	Task 1	Task 2	Subject Number	Task 1	Task 2	Subject Number	Task 1	Task 2
F1	24	30	T1	29	21	C1	14	23
2	30	30	2	11	19	2	15	11
3	14	11	3	22	11	3	10	10
4	18	13	4	30	30	4	10	11
5	11	11	5	30	29	5	14	30
6	30	30	6	30	30	6	13	11
7	30	13	7	30	30	7	10	10
8	30	30	8	11	10	8	10	10
9	30	20	9	12	11	9	10	30
10	11	10	10	15	13	10	21	10
Mean	22.8	19.8	Mean	22.0	20.4	Mean	12.7	15.6

Table 3. Overall alternations as a percentage of total number of trials to criterion in Experiment1. (Discrimination Learning)

FRONTALS			TEMPORALS			CONTROLS		
Subject Number	Task 1	Task 2	Subject Number	Task 1	Task 2	Subject Number	Task 1	Task 2
F1	21	8	T1	10	14	C1	14	17
2	20	24	2	0	15	2	13	0
3	14	0	3	9	0	3	0	0
4	11	0	4	13	23	4	0	0
5	0	0	5	3	7	5	14	13
6	20	23	6	13	13	6	7	0
7	20	7	7	20	23	7	0	0
8	17	17	8	0	0	8	0	0
9	20	0	9	9	9	9	0	17
10	0	0	10	13	0	10	14	0
Mean	14.3	7.9	Mean	9.0	10.4	Mean	6.2	4.7

There are however alternative means of exploring the pattern of results in the three groups. The sensory disinhibition hypothesis predicts greater distraction effects for the frontal group in Task 1. There is a number of ways in which this can be tested. The tendency to alternate from correct to incorrect cues should differ, for example. According to the sensory disinhibition hypothesis alternations should be relatively greater in Task 1 compared with Task 2 for the frontal lobe group. Since there was considerable variation in the total number of trials to criterion it was decided to express alternations as a percentage of the total number of trials to criterion. A simple count of the number of times the subject changed from a correct to an incorrect cue was made, and is presented as a percentage of the total number of trials to criterion in Table 3.

Using planned comparisons a Two Way Nested Analysis of Variance (3 x 2) was accordingly conducted on these scores. There were no overall significant main effects due to Task or Lesion, but when the scores for the two brain damaged groups are analysed separately, the Lesion x Task interaction reaches significance ($F = 4.45$, $p < 0.025$, one tailed test). A summary table is presented in Appendix D. It appears that in accordance with the prediction frontal lobe subjects alternate disproportionately more often in Task 1 than Task 2 compared with temporals. The hypothesis that frontals are more severely impaired than temporals when the opportunity for distraction is greater may therefore be accepted.

Another way of examining the consequences of distraction is by considering the number of "post-search errors" - the number of times the subject chooses incorrect cues after having chosen the correct one, before criterion is reached. The number of "post-search errors" was therefore calculated for each "stage", and the sum of these expressed as a percentage of the total number of trials to criterion. These results are shown in Table 4. (The raw data may be found in Appendix N.)

A Two Way Nested Analysis of Variance was carried out on these data, the results of which are presented in summary in Appendix E. Once again, although the main effects of Task and Lesion failed to reach significance, a significant Lesion x Task interaction for the frontal and temporal group scores emerged ($F = 8.17$, $p < 0.01$, one tailed). This suggests that frontal lobe patients make a far greater percentage of post-search errors in Task 1 in comparison with Task 2, while the reverse is true for temporals, supporting the sensory disinhibition hypothesis of frontal lobe function.

Finally, a count was made of the total number of novel discriminanda selected by the two groups in Task 1. These are presented in Table 5 as a percentage of the maximum possible number which each subject could have chosen. (The raw scores are presented in Appendix O.) Thus a subject who chose all the novel stimuli on the board

Table 4. Overall post search errors as a percentage of the total number of trials to criterion in Experiment 1. (Discrimination Learning)

FRONTALS			TEMPORALS			CONTROLS		
Subject Number	Task 1	Task 2	Subject Number	Task 1	Task 2	Subject Number	Task 1	Task 2
F1	21	0	T1	17	14	C1	14	26
2	20	20	2	0	5	2	13	0
3	0	0	3	5	0	3	0	0
4	33	0	4	70	63	4	0	0
5	0	0	5	0	52	5	0	13
6	20	8	6	17	77	6	0	0
7	33	8	7	43	57	7	0	0
8	77	30	8	0	0	8	0	0
9	57	0	9	8	0	9	0	17
10	0	0	10	7	0	10	19	0
Mean	26.1	6.6	Mean	16.7	26.8	Mean	4.6	5.6

Table 5. Total number of incorrect alternatives selected as a percentage of the maximum possible number in Experiment 1. (Discrimination Learning)

Subject Number	Frontals	Subject Number	Temporals	Subject Number	Controls
F1	16	T1	36	C1	4
2	19	2	0	2	16
3	16	3	24	3	0
4	8	4	75	4	0
5	0	5	31	5	8
6	100	6	78	6	8
7	69	7	78	7	0
8	100	8	0	8	0
9	100	9	0	9	0
10	0	10	8	10	12
Mean	42.8	Mean	33.0	Mean	4.8

but who failed to get further than for example Stage 2 nevertheless receives a score of 100%. In effect, this is a measure of the range of cues sampled. A Kruskal Wallis Analysis of Variance was conducted on these scores and a value of $\hat{H}$ of 6.41 obtained. This is significant ($p < 0.05 > 0.025$). But although the direction of the difference between the frontal and temporal lobe group scores is in line with prediction, a Mann Whitney test carried out on these subjects' scores alone yielded a value of U of 35.5, which is insignificant ($p > 0.05$).

The possibility that differences other than locus of brain lesion contributed significantly to the performance of the two groups of subjects was also considered. In fact the average age of the two groups and postoperative interval between surgery and testing as shown in Appendix A were not found to differ significantly using a Mann Whitney test ($p > 0.05$). In addition, taking both sets of patients together, no reliable correlations were found between the total number of trials to criterion and either age ($r = -0.29$, $t < 1$), or the length of time which had elapsed since the lesions had been sustained ($r = +0.02$, $t < 1$). The relationships between post-search errors and age, and post-search errors and time since operation were also insignificant ($r = -0.13$, $t < 1$, and $r = +0.21$, $t < 1$ respectively). The effect of lesion size was assessed by sorting the patients into 3 groups according to whether the area of damage was considered by the experimenter to be relatively small, medium or large. A Jonckheere's trend

test was then carried out on the total number of trials to criterion for the subjects in these three groups but there was no significant tendency for the scores to increase with lesion size ($p > 0.05$). These results suggest therefore that the performance of the frontal and temporal lobe patients cannot be related systematically to differences in age, opportunity for compensation following surgery, or the severity of the lesions received.

In addition to the tests of the sensory disinhibition hypothesis which have been described, an attempt was made to assess the proportion of perseveration errors in the three groups following the suggestion made by Milner and others that errors of this type should be more frequent in the frontal lobe group. The number of occasions that subjects selected the same incorrect cue on successive trials was therefore calculated and expressed as a percentage of the total number of trials to criterion. These data are presented in Table 6. (The raw data may be found in Appendix P.)

The number of perseverative errors produced by the control group was so small that these errors were excluded from any further analysis. A Two Way Nested Analysis of Variance (2 x 2) was conducted on the scores for the two brain-lesioned groups, but since all F ratios obtained were less than unity the hypothesis that frontal lobe damage is associated with an abnormally high level of perseverative responding cannot be accepted. (See Appendix F.)

Table 6. Overall perseverative errors as a percentage of total number of trials to criterion in Experiment 1. (Discrimination Learning)

FRONTALS			TEMPORALS			CONTROLS		
Subject Number	Task 1	Task 2	Subject Number	Task 1	Task 2	Subject Number	Task 1	Task 2
F1	21	40	T1	21	5	C1	0	9
2	12	20	2	0	16	2	0	0
3	0	0	3	0	0	3	0	0
4	28	15	4	23	27	4	0	0
5	0	0	5	37	28	5	0	7
6	13	20	6	30	23	6	8	0
7	17	0	7	37	7	7	0	0
8	37	17	8	0	0	8	0	0
9	30	45	9	0	0	9	0	30
10	0	0	10	13	15	10	29	0
Mean	15.8	15.7	Mean	16.1	12.1	Mean	3.7	4.6

In all therefore the results obtained suggest that frontal subjects do differ in certain respects from temporals in their reaction to the discrimination learning tasks i.e. in the percentage of times they alternate from the correct to the incorrect cue and the percentage of post search errors they produce. Moreover in general the pattern of choices and types of error which they make support the sensory disinhibition hypothesis of the frontal lobe deficit. It must also be pointed out however that in other respects i.e. trials to criterion, percentage of novel discriminanda selected and perseverative errors, frontal and temporal lobe subjects are indistinguishable from one another and do not behave in noticeably different ways.

Experiment 2. Visual Search

The results of the visual search experiments are presented in Table 7.

The scores in Table 7 were first of all converted to reciprocals to reduce the effect of extreme scores (Edwards, 1967) and three separate Two Way Nested Analyses of Variance were carried out as indicated.

(i) Size of positive set (Comparison A, Table 7)

The main effects of Lesion and Positive Set (i.e. Target) Size were confirmed as significant ($F = 4.51$, $p < 0.01$, $F = 33.86$, $p < 0.001$, respectively, for one tailed tests), the latter result supporting the general trend obtained for normal subjects (Neisser, 1963). There was no significant

Table 7. Mean total search times in seconds in visual search experiment. (Experiment 2)

Subject Group	Subject Number	A / C: Targets 4 / 22 subset	A / C: Targets 2 / 24 subset	A / B: Target 1 / 25 subset	B: Target 1 / 15 subset	B: Target 1 / 5 subset	C: Target 2 / L/N subset
FRONTALS	F1	22	18	11	6	4	34
	2	131	22	23	74	24	12
	3	26	83	13	11	6	10
	4	35	16	17	16	13	62
	5	83	25	10	10	19	15
	6	78	47	8	7	22	58
	7	96	37	8	6	14	41
	8	88	79	17	19	12	50
	9	67	60	9	18	14	54
	10	49	23	13	9	16	28
	Mean	67.5	42.0	12.9	17.6	14.4	36.4
TEMPORALS	T1	67	67	12	16	19	23
	2	28	71	12	16	14	12
	3	56	37	8	9	21	34
	4	27	38	5	12	4	21
	5	170	100	29	54	56	130
	7	48	24	3	12	18	29
	8	19	19	13	20	10	73
	9	81	28	7	14	5	57
	10	30	37	6	11	14	115
	Mean	58.6	46.8	10.6	18.2	17.9	53.8
CONTROLS	C1	41	29	17	13	14	34
	2	37	14	19	4	4	17
	3	45	36	8	11	15	21
	4	84	19	2	4	6	15
	5	25	7	4	3	2	19
	6	9	42	4	10	8	13
	7	34	24	9	8	8	19
	8	44	42	7	15	3	19
	9	92	10	7	10	7	10
	10	20	56	4	4	3	12
	Mean	43.1	27.9	8.1	8.2	7.0	17.0

Comparison A — Size of Positive Set

Comparison B — Size of Negative Set (Subset)

Comparison C — Number of different types of targets

Lesion x Task interaction effect however ($F = 1.91$, $p > 0.05$), and tests for specific comparisons showed that although there is a significant difference between the means of the two brain lesion groups taken together, and the control group ($F = 8.52$, $p < 0.01$, one tailed test) the difference between the temporal and frontal lobe group means fails to reach significance ($F = 1.38$, $p > 0.05$).

(ii) Negative set size (Comparison B, Table 7)

The effect of negative set population size did not reach significance ($F = 1.05$, $p > 0.05$), a result which fails to confirm Rabbitt's (1967) findings. A significant main effect of Lesion was found however ($F = 6.89$, $p < 0.01$, one tailed test) and specific comparisons once again yielded a significant result for the control versus frontal and temporal comparison ($F = 13.56$, $p < 0.001$, one tailed test) but no significant difference between the frontal and temporal group means alone ($F > 1$).

As with the Analysis of Variance for comparison A these results suggest a general increase in search time on account of the effect of brain damage per se, but no selective impairment due to locus of lesion. The sensory disinhibition hypothesis thus receives no support from these data.

As a whole these results did not duplicate Teuber's (1964) findings referred to earlier. In fact the overall mean search time for the two brain-lesioned groups was 31.8 seconds for the frontal and 34.3 for the temporal, the

reverse of what might be predicted from Teuber's (1964) data, which were obtained from patients with lesions located in the posterior cortex and frontal lobe.

(iii) Positive set class size (Comparison C, Table 7)

A significant main effect of Lesion was found for the results of this comparison ($F = 4.07$, $p < 0.025 > 0.01$, one tailed) but the absence of any interaction fails to uphold the prediction derived from Costello's (1956) data that frontals will find the two target"letter-number" combination more difficult than the two letter condition compared with temporals and controls. The overall group means were assessed using planned comparisons and a value of F of 7.89 was obtained for the control group versus frontal and temporal group comparison ($p < 0.01$, one tailed test). In line with previous comparisons this supports the view that there are general effects due to the presence of a brain lesion but no locus specific impairments.

The Task main effect was significant ($F = 5.53$, $p < 0.05 > 0.025$, two tailed test). That is to say, subjects as a whole appear to have found the letter number condition easier than the two letter search condition.

Summary tables for all these analyses may be found in Appendix G.

That brain damage itself exerts a detrimental effect on search time is beyond doubt, but in all conditions of search studied, the performance of the frontal lobe group is

indistinguishable from that of the temporals. The results of the visual search experiments therefore neither provide support for the sensory disinhibition hypothesis nor do they parallel those reported by Teuber.

Experiment 3. Classification (card sorting)

Total sorting time for the eight conditions investigated are presented in Table 8. As with the visual search data these scores were first of all converted to reciprocals and a 2x2x2 Analysis of Variance suitable for the 4 way design nested on one variable (Lesion group) was then carried out (see Appendix H).

The Lesion main effect just reaches significance ($F = 2.89$, $p < 0.05 > 0.025$, one tailed). On the other hand none of the lesion interactions proved significant (all F ratios for these were less than unity with the exception of the Lesion x Number. In this case $F = 1.24$, $p > 0.05$, two tailed). The sensory disinhibition hypothesis therefore receives no support from the present experiment.

The analysis confirmed the main effects of Position ($F = 72.57$, $p < 0.001$, one tailed test) and Novelty of extraneous background material ($F = 45.73$, $p < 0.001$, one tailed) as significant. This suggests that subjects as a whole find the variable target more difficult than the fixed target condition and that varying the irrelevant material on each card produces an increase in overall sorting times. In summary however, despite the demonstration (only

Table 8. Total sorting times in seconds for the eight packs of cards in Experiment 3. (Classification)

Target position		Fixed				Variable			
No. of irrelevant stimuli		2		8		2		8	
Novelty of irrelevant stimuli		Same	Diff.	Same	Diff.	Same	Diff.	Same	Diff.
Group	Subject Number								
FRONTALS	F4	32	38	29	34	31	42	31	37
	5	26	28	26	31	26	43	30	35
	6	33	33	32	32	33	37	34	39
	7	61	66	68	70	78	107	59	73
	8	32	35	34	32	35	47	42	51
	9	42	46	41	48	48	47	44	53
	10	29	29	29	29	38	38	32	40
	Mean	36	39	37	39	41	52	39	47
TEMPORALS	T1	43	47	49	41	43	73	44	53
	2	30	32	31	30	32	35	33	44
	3	33	31	33	33	41	39	38	39
	4	69	68	57	61	71	90	66	77
	5	62	68	64	70	56	84	75	81
	7	25	30	27	30	34	45	31	41
	8	28	27	29	29	32	52	33	43
	9	28	40	29	32	38	36	31	34
	10	48	43	51	46	47	93	47	52
	Mean	41	43	41	41	44	61	44	51
CONTROLS	C1	24	20	26	25	25	26	28	29
	2	27	27	26	25	25	26	24	30
	3	30	29	31	33	34	39	31	37
	4	28	38	30	30	42	44	29	41
	5	21	25	25	27	23	25	27	27
	6	33	34	33	39	37	38	41	37
	7	34	35	34	39	38	36	37	43
	8	41	31	35	40	32	84	35	53
	9	35	38	38	34	38	53	41	47
	10	27	32	29	28	33	32	34	37
	Mean	30	31	31	32	33	40	33	38

moderate in this case) of a general increase in sorting speed in the brain damaged groups compared with controls the results of this experiment did not indicate any locus specific effects consistent with the sensory disinhibition hypothesis.

Discussion

Experiment 1. Discrimination Learning

These experiments provide limited support for the sensory disinhibition hypothesis in that certain aspects of the results suggest, as predicted, that frontals find Task 1 more difficult than Task 2 whereas the reverse seems to be true of the temporal lobe group. However these results are not nearly so clear-cut as was the case with Buffery's results with baboons, and at first sight may be said to imply little parallel between the frontal lobe deficit in man and other primates. On the other hand Buffery's subjects received extensive bilateral damage and different measures of performance were taken (measures which in fact would have been unsuitable for subjects in this study).

The material used in these experiments also differed from that used by Buffery because of the attempt made to restrict the stimulus dimensions. However these differences in the type of material used may have been important. Whereas Buffery used multi-dimensional stimuli (plastic toys) which had presumably never been seen by his subjects, the stimuli in the present experiment were novel to human beings

only in an academic sense. For human subjects they were not, apparently, a powerful source of distraction which seems to have been the essence of the novelty effect produced by Buffery's stimuli. To have used comparable material in this experiment, however, would have destroyed its more formal structure and almost certainly made the problems too simple.

There are further points which may be made. The first is that the frontal subjects could subjectively be divided into two groups - those who clearly were relatively severely impaired and whose general performance suggested that they could be profitably studied in further detail on variations of the same task, and those whose performance compared favourably with controls but who might show deficits with more sensitive methods of analysis. (The subjects' social behaviour also contributed to this impression.) Possibly this lends support to the selected single case study approach advocated by, for example, Luria, but it also suggests that the measures employed in this experiment may not be the most sensitive or appropriate. For example, no note of the time required to solve the discriminations was taken. It may have been that there were differences in this. Frontals of the second "type" may well be more distracted by the incorrect discriminanda but be able to overcome this if given time. This is consistent with (and reminiscent of) the suggestions made by Pribram and Luria that mechanisms of habituation are disturbed in frontal lobe damage. Individual "cognitive

styles" may also be important in the sense that a subject's response to a disturbance could take the form of making frequent impetuous decisions or of pausing and carefully assessing the evidence, thus taking longer. Such considerations create difficulties for any attempt to measure behaviour of course but seem particularly relevant in the present context.

As far as the present experiment is concerned a number of improvements suggest themselves. To begin with, the whole procedure needs to be speeded up. This could be done by dispensing with the board and separate cards and preparing a set of large cards with the necessary information presented on them at various positions. Each of these "boards" could then be shown in turn to subjects, minimising the time spent in retrieving and presenting the cards individually. A note could also be taken of the subject's decision time from the moment each board is presented.

Experiment 2. Visual Search

The main difficulty with this experiment was probably that clinical subjects do not seem to behave in the well-mannered way in which normals are reputed to do. In this experiment they often paused to ask questions and did not readily follow the instructions which had been given. For the majority of subjects of course, this was an unusual situation but the general lack of predictability in their reaction to the task did make it difficult to measure performance accurately. Although every attempt

was made to approximate the careful studies of Neisser and others there were very large individual differences in performance.

One difficulty in particular apparently stemmed from the fact that only one target was present in the list. This led many subjects to develop hypotheses about its likely position even though they had been told that this was randomly determined. As well as contaminating the results this also introduced a kind of competitive element which may possibly have proved detrimental to certain subjects who seemed to regard the task as something of a subject-experimenter battle of wits.

These remarks suggest that, as with the discrimination learning experiments, the situation requires a much greater degree of control in order to reduce error variation. One possibility would be to present the material sequentially and to measure decision time for each item. Alternatively a letter cancellation task could be used with the target letters occurring fairly frequently. Not only would this provide a useful form of error analysis ("False positives" and "Incorrect rejections" could be measured independently) but in addition the notion of search time as a measure of performance would itself have more meaning.

Experiment 3. Classification (card sorting)

There was evidence in this experiment of a significant level of impairment in the brain-damaged groups compared with controls but no suggestion of any selective impairment due to anatomical locus of lesion. This parallels the results of the visual search experiments.

Most subjects enjoyed this experiment, suggesting that basically it may be a useful sort of technique for clinical subjects of this type. On the other hand, the fact that it was an experimental situation in which there was essentially much more moment-to-moment control over what the subjects actually did suggests that the results of the other experiments may not after all have been much influenced by a more precise control of the subjects. However once again decision times for cards presented individually might provide a more accurate measure of the extent to which the subjects' identification of the target shapes had been disturbed by the various experimental conditions.

The failure of the experiment as a whole to demonstrate any selective effects due to frontal lobe damage raises the question of whether the conditions of "high distractibility" in this experiment are really analogous to the conditions which produced maximum impairment in Buffery's frontal baboons. That is to say, although the position of the shapes was constantly varied, the cards have an appearance of uniformity. It is more difficult to identify the target shape in the "novel" conditions but this seems to be

a question of discriminability. There is no impression that the targets are difficult to find because they are surrounded by stimuli of greater novelty value. This issue is taken up again in the follow up series of experiments discussed in the next chapter.[1]

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[1] In this first set of experiments 10 patients with frontal lobe lesions have been compared with 10 temporal lobe cases. However it is also possible to examine the data for hemispheric differences by rearranging the subjects according to whether their lesions are located in the left or right hemisphere. When this is done there are 7 cases of right and 10 cases of left hemisphere damage. The total trials to criterion for these subjects in the discrimination learning experiment were analysed using Analysis of Variance. No significant F values were obtained (see Appendix I). The visual search data were re-examined by obtaining the subjects' overall mean total search time from all conditions and analysing these scores with an unrelated 't' test. The means for the right and left hemisphere groups were 24.43 and 41.07 seconds respectively. A value of 't' of 2.11 was found, which just fails to reach significance at $p < 0.05$ ($t = 2.13$, $p < 0.05$, two tailed test). However if the prediction is made that left hemisphere patients should take longer because of the task's verbal element, making a one tailed test justified, the difference is clearly significant. The mean sorting times in the card sorting experiment were reallocated and treated in the same way using an unrelated 't' test. The means were 39.80 and 47.88 seconds for the right and left hemisphere groups respectively, but these were not found to differ significantly ($t < 1$).

Chapter Five

The Follow-up Study

Introduction

The main aims of the second series of experiments were:

(i) to determine whether a measure of performance found to discriminate between frontal and temporal lobe patients in the first study was of any value in predicting performance in other cognitive tasks.

(ii) to extend the range of inquiry into the sensory disinhibition hypothesis.

Two conclusions from the first study were also taken into account in designing these follow-up experiments. To begin with, in the first study stimulus uniqueness was controlled in the discrimination learning experiments in such a way that the "novelty value" of the materials employed was minimal in comparison with the multidimensional stimuli used by Buffery. Clearly, the reaction of frontal lobe patients to stimuli of comparable novelty would provide a useful further test of the sensory disinhibition hypothesis. In addition, due to the rather variable performance of neurosurgical patients generally, a much greater degree of control is perhaps needed over which the subject is required to do in order that the effects of momentary lapses of attention should be minimized.

Method

Subjects

As the principle aim of this next series of experiments was to make comparisons among frontal lobe patients, no normal control group was tested and only a small group of patients with temporal lobe lesions was included for comparison. The patients were selected as before from the outpatient list of the Neurosurgical Department of the London Hospital, Whitechapel. Most of the temporal lobe cases took part in the first study whereas the frontal patients had neither been tested previously nor had they been invited to participate in the first study. The same criteria as before were used in selecting these subjects. There was a slight difference in the way in which appointments were arranged for the testing sessions in that all patients were given the alternative of either attending the London Hospital or doing the tests in their own homes. Most patients preferred to be tested at home and there was therefore considerable variation in the experimental conditions. In addition, all patients were offered a "fee" of £1.00 for their assistance, and those who came to the Hospital also received their travelling expenses.

Details of the patients (F11-20, T1,4,8,9,11) are to be found in Appendix A and the surgeon's reconstructions of the locus and extent of their lesions in Appendix B.

Experiment 4. Serial Learning

Introduction

The performance of frontal lobe patients on conventional memory tasks has not been explicitly studied in relation to the sensory disinhibition hypothesis. Luria (1973), however, has argued for a serial learning deficit in frontal subjects and Pribram (1969) suggested a breakdown in a "parsing" mechanism as the basis for delayed alternation failure in monkeys with frontal lesions. "Parsing" appears to refer to the process of organizing incoming information so that its temporal structure is preserved and stored correctly. Such a mechanism is clearly important in the acquisition of, for example, lists of words which are to be recalled in the order in which they were originally presented.

This experiment was influenced by Milner's (1971) proposal that frontal lobe patients are impaired when required to switch from one situation to another. It was felt that this notion could be usefully combined with the sensory disinhibition hypothesis, and the use of a technique for studying serial learning in normal subjects described by Gordon and Fenoulhet (1971) suggested itself. In this experiment, lists of eight spoken digits were presented for immediate recall. Irrelevant "distractor" items which the subjects were not required to retain were interpolated between these digits. According to the sensory disinhibition hypothesis the nature of the distracting items should be an important determinant of the performance of frontal lobe subjects. The more "novel"

and the more variable, the greater the reduction in retention of the relevant items predicted for the frontal lobe group in comparison with controls. Moreover the extent to which frontal subjects' performance is affected in this task should be related to a feature of the previous frontal group's performance in the discrimination learning experiments reported earlier. That is to say the "Post-search errors" for these subjects, which were taken to reflect their greater susceptibility to distraction, should be positively correlated with the effect of increasing irrelevant item variability. Gordon and Fenoulhet (1971) used single letters as "distractors", and it was decided to adopt this procedure here.

Design

Ten lists each containing six digits and six "distractor" letters arranged alternately were drawn up. (It was felt that longer lists would be too difficult for clinical subjects.) In half the lists (the high distractibility condition) all the letters were different from each other, while in the remainder (the low distractibility condition) the same letter was repeated six times. Two additional lists of each type were also prepared, one to be used as an example for the subject, and the other as a practice list. Letters and digits were selected randomly with the constraint that no letter or digit was repeated within a list. The letters I and O and the digit 0 were

avoided to prevent confusion. Each list began with a digit and therefore ended with a letter.

The ten lists were presented to the subjects in a randomly determined order in two blocks of five as part of the series of tasks which was administered. The lists used are presented in Appendix J.

Materials

The subject was provided with a pencil and a card divided into columns in which to record his responses.

Procedure

The subject was told that the experimenter would read out a list of letters and numbers and that he was to ignore the letters and just remember the numbers. The appropriate example list was then read out to him and the method for writing down his responses on the card was explained. He was told to write down the numbers in the order in which they had been presented and to leave a space if he could not recall the item for any particular position. No instructions about guessing were given. The subject was also told not to begin writing until the final item had been read out, something which would be indicated by a light tap of the experimenter's pencil on the table. After attempting the practice list, a check was made that the subject understood the instructions and was carrying them out correctly. The rate of presentation was approximately one item every $\frac{3}{4}$ sec.

Experiment 5. Delayed Paired Comparison

Introduction

The aim of this experiment was not, as the title might suggest, to investigate memory processes in frontal lobe patients but to examine the effect on performance of stimuli which may be thought of as really novel, at least in the context of the experiment, and therefore of high distractibility value. The sensory disinhibition hypothesis predicts that novel stimuli should have relatively more effect on the behaviour of frontal lobe patients than controls. In addition, if the discrimination learning impairment found for frontal subjects in the first study arises from increased sensory disinhibition, the extent of the "novelty effect" in this experiment should be related to the Post-search errors for each subject.

Design

In the method of delayed paired comparisons the subject is required to decide whether the second of two stimuli, presented in succession, is the same as or different from the first. This method was selected for a number of reasons. To begin with, it is a sequential task and therefore provides an opportunity for presenting novel stimuli suddenly against a background of familiar ones. It also ensures that the subjects attend to the material at all times, and permits measurement of a sensitive dependent variable, decision speed.

The experiment was designed so that in the first part (Trials 1-10) the subject saw only a small number of familiar stimuli, i.e. simple designs which occurred in pairs in various combinations. The shapes were a plain white circle, square and cross drawn in pencil. In the second part (Trials 11-26) of the experiment a number of novel stimuli was presented as comparisons in four different ways (see below). The novel stimuli were coloured pictures cut from magazines and in the case of those which appeared on "different" trials consisted of a lion, an ornate teapot, a saloon car and a lampshade.

Familiar stimuli were arranged in pairs randomly so that half the comparisons required the response "same" and half "different". A fresh set of pairings was used for each subject. In the first part of the series (Trials 1-10) subjects saw pairs of familiar stimuli, and in the second part (Trials 11-26) the four trials in which novel stimuli occurred were mixed with 12 more trials in which combinations of the familiar stimuli were again used. In all therefore, there were 26 pairs of stimuli.

The order in which the "novel" trials occurred was randomized for each subject. One novel trial was always placed at the beginning of the second part of the series (i.e. Trial 11) and it was arranged that the other "novel" trials would be separated from each other by either three, four or five "familiar" trials. The final trial was also always a novel one. Separate spacing schemes were arranged for each subject by randomization of the three intervals mentioned.

The four novel trials were as set out below:

Presentation	Stimulus First	Stimulus Second	Correct Response
Type of stimulus	Familiar	Novel	Different
	Novel	Familiar	Different
	Novel	Novel	Different
	Novel	Novel	Same

The "same" novel pairing consisted of two identical pictures of a mug of tea.

It is difficult to see how the lack of balance inherent in this arrangement (three "different" responses and only one "same") might be rectified apart from including more novel-novel "same" pairs. In view of the basic aim of the experiment however, presumably the fewer novel stimuli presented, the better.

A sample protocol for one subject is given below:

Trial	Stimulus First	Stimulus Second	Trial	Stimulus First	Stimulus Second
1	Circle	Square	14	Square	Circle
2	Square	Circle	15	Circle	Circle
3	Cross	Cross	16	Teapot	Square
4	Circle	Cross	17	Square	Square
5	Circle	Circle	18	Cross	Circle
6	Cross	Circle	19	Circle	Square
7	Square	Cross	20	Cross	Cross
8	Square	Square	21	Square	Square
9	Circle	Circle	22	Cross	Car
10	Square	Square	23	Circle	Circle
11	Lion	Lampshade	24	Cross	Circle
12	Square	Cross	25	Cross	Square
13	Cross	Cross	26	Mug	Mug

The subject responded by pressing one of two morse keys marked "same" and "different". The position of these (i.e. either on the left or the right) was alternated for each subject.

Materials

The familiar stimuli, which were drawn with a pencil, measured approximately two inches across and appeared on plain white cards measuring five inches by six. The novel stimuli were pasted in the centre of cards of the same size. Holes were also punched in each card so that they could be presented as a series in a ring file. When arranged in the file each pair was separated by a pink card while each member of a pair was separated by a plain white card.

Because of the special circumstances of testing, the apparatus used to measure the subject's decision time for each trial was inevitably less sophisticated than would have been the case had the experiment been conducted in the laboratory. It consisted of three morse keys wired to an event recorder of the pen and paper tape variety. Each key was wired to a separate pen so that when the key was pressed the pen would make a corresponding mark on the moving tape. The experimenter had one key and the subject two (one labelled "same", the other "different"). When the second of the two stimuli in any trial was presented the experimenter's key was pressed and the subject's decision speed was taken to be a function of the distance between the two relevant marks on the tape. As the experimenter was required to coordinate the pressing of his key with the presentation of the cards, some variability in the accuracy of these measures is bound to have arisen. It is thought that the recording technique was accurate to within $\frac{1}{2}$ sec.

Procedure

The subject was told that he would be shown a number of designs in pairs and that he was to decide whether the second one was the same as or different from the first by pressing the appropriate key. The subject was instructed to use the same (preferred) hand for pressing both keys. A small number of practice cards was then presented, to familiarize the subject with the task. The subject was also encouraged to respond as quickly as possible but at the same time to try not to make any mistakes. After the tape roller had been switched on the first design was exposed for approximately two seconds followed after approximately $2\frac{1}{2}$ seconds by the second. As this was presented the experimenter activated his morse key using his foot. The next pair was presented immediately after the subject made his response. As each card was turned over the experimenter described it out loud as either "the first one" or "the second one". Apart from pauses which occasionally occurred when the subject realized he had made an error the continuity of the series was maintained and no indication was given that at some point different sorts of stimuli were to be presented.

Experiment 6. Conflicting Stimuli

Introduction

In the delayed matching from sample experiments reported by Buffery (1964), baboons with frontal damage were found to take longer than temporals to make the initial response to the "sample stimulus". There was also

an impairment of performance as the number of alternative matching stimuli, rear-illuminated panels of uniform colour (hardly to be thought of as "novel"), was increased. Thus even in the absence of incorrect novel alternatives there appear to be difficulties in the registration of specific stimuli, giving rise to increased response latencies. This suggests that novel stimuli may be thought of as aggravating an underlying disturbance of attention. The possibility that this holds for frontal lobe damage in man was explored in this experiment which investigated the performance of frontal lobe patients in a selective attention task presenting conditions of minimal novelty.

In addition, there is also the related question of the extent to which irrelevant distracting stimuli are actually analyzed. This is something of a contentious issue in current experimental investigations of selective attention in normal subjects and dichotic listening studies have still not resolved the problem of the type or level of analysis which the "rejected message" receives. As far as the attention deficit in frontal lobe damage is concerned, however, the evidence from Buffery (1964) suggests that irrelevant stimuli undergo moderate levels of analysis since novel ones produce more impairment than familiar ones. This would not be expected if the effect of frontal lobe damage were simply to cause the animal to respond to any form of stimulus. Sensory disinhibition therefore appears to do more than merely enhance surrounding stimuli and the impairment of attention which is produced seems to involve

higher order functions. On the other hand, as far as stimulus novelty is concerned Buffery's results were obtained in a situation where the position of all the discriminanda was constantly being changed, making it more likely that the animals would notice the incorrect stimuli when searching for the rewarded one. An alternative method would be for the position in which relevant stimuli are presented to remain constant and at the same time for distracting stimuli to be displayed at surrounding points. If an impairment is still observed this would parallel the results of Buffery's delayed matching from sample experiments. In addition it should be possible by appropriate selection of the irrelevant stimuli to examine the type of analysis, if any, which they receive. If some of the stimuli appearing in the "irrelevant" position are actually relevant to the task they are more likely to be processed than items which are not relevant and therefore should be more interfering. The effect should also be related to the subjects' Post-search error scores, if these do in fact constitute a measure of susceptibility to distraction. In summary therefore, this experiment set out to investigate the effect of presenting task-relevant, as opposed to task-irrelevant, information in a position which subjects had been instructed to ignore. Like the visual search experiment (Experiment 2), it makes the assumption that familiar stimuli such as letters have little or no "novelty" value, especially if they occur frequently within the same task.

Design

In designing this experiment, it was decided once again to use a continuous task to ensure reasonable control over the subject's attention, and to use decision speed as the dependent variable. The overall intention was to provide subjects with a simple two-choice task in which stimuli relevant to the decision were presented on certain trials in position where subjects' attention was not supposed to be focussed. Subjects were therefore required to respond to a letter which appeared on the right hand ("relevant") side of a piece of card by pressing one or other of two morse keys. The letter could be either an "a" or "b". In one condition the left hand ("irrelevant") side of the card remained blank. In the second condition however the cards showed either the letter "a" or "b" on the irrelevant side (as well as the relevant), and in the third condition the letter "c" was presented on the irrelevant (and again either "a" or "b" on the relevant).

In each condition half the cards had "a" displayed on the relevant side, and half had "b". As far as the second condition was concerned, the letter appearing on the irrelevant side always conflicted with the one appearing on the relevant. There were 10 cards in each condition making 30 in all, and these were presented to subjects in a randomly determined order. The position of the keys which the subjects were required to press was alternated for each subject.

Materials

Plain white cards measuring approximately eight inches by four were used. These were divided into two halves by a faint pencil line drawn from top to bottom (see Figure 6). The letters were drawn with "Letraset" and measured $\frac{3}{4}$ inches in height. The cards had holes punched in them so that they could be presented in a ring file. A pink card was inserted between each one to avoid anticipation of the next trial.

The subject responded by pressing one of the morse keys which were marked "a" and "b". The apparatus for recording the subject's speed of decision was the same as has been described in Experiment 2.

Procedure

The instructions to the subject were that he would be shown a series of cards such as he could see in the file (at this point one of the cards from the middle of the series, always with the irrelevant side blank was shown to the subject) and that he should respond as quickly as possible to the letter appearing on the right hand side by pressing the appropriate key, using the same (preferred) hand for each. The subject was told to ignore anything else which appeared on the card, and, as before to avoid errors as far as possible. A short series of cards showing simply either "a" or "b" was then shown to familiarize the subject with the position of the "a" and "b" keys. The

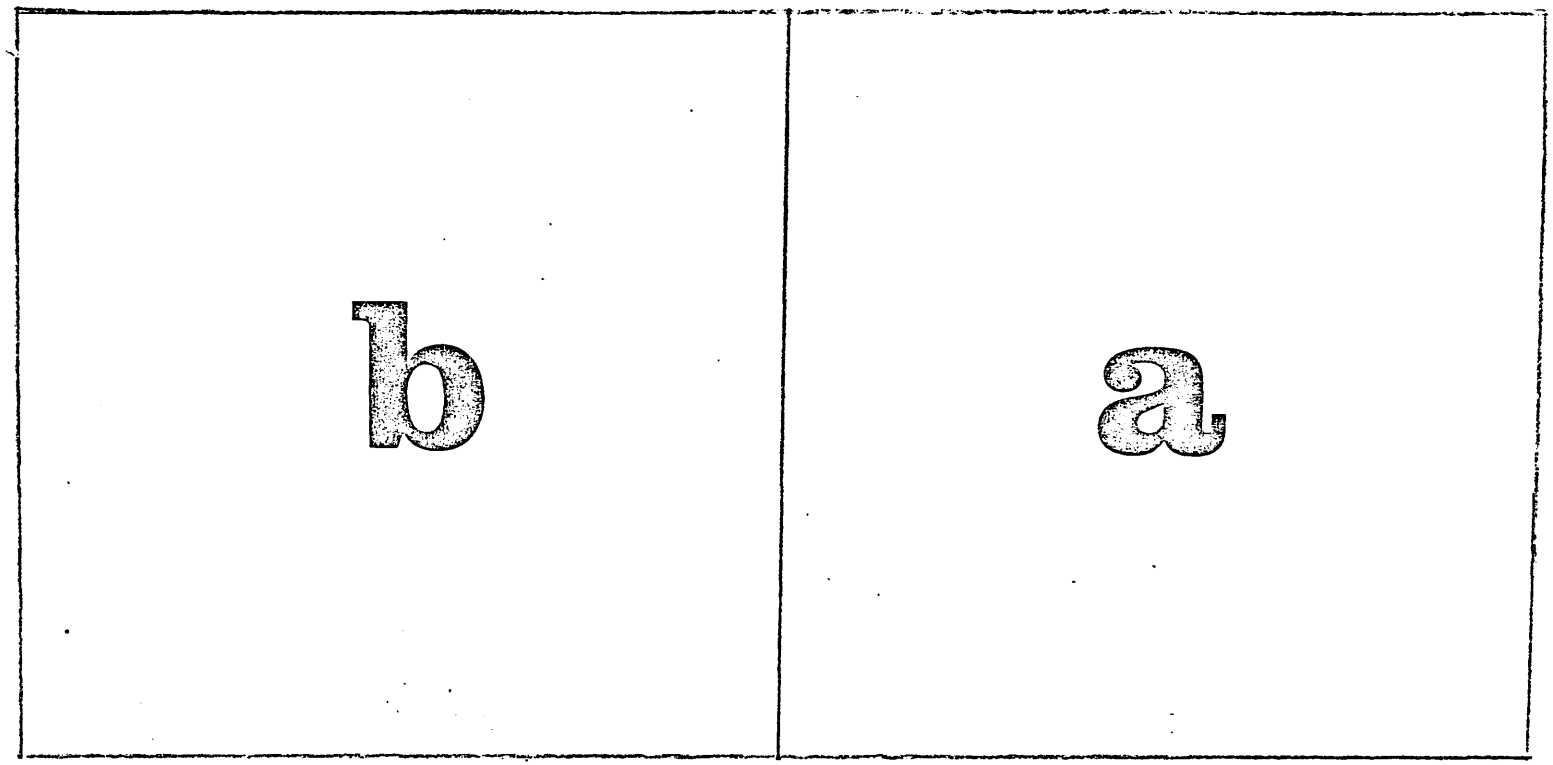

Figure 6. One of the cards used in the Conflicting Stimuli Experiment

thirty cards were then exposed to the subject, the method for recording decision times being the same as for Experiment 5.

The rate at which the cards were turned over was governed by the subject's progress but for most subjects was in the region of one card every two seconds.

In addition to these three tasks, subjects who had not been tested before (i.e. the frontal lobe group and one temporal lobe case) were also given Task 1 of the discrimination learning experiments reported in the first study in order to establish a Post-search error for use in statistical comparisons. The order in which the various tasks was presented was arranged according to a random schedule.

In both experiments 5 and 6, trials on which errors occurred were excluded from the statistical analysis.

Results

Discrimination Learning (Task 1, Experiment 1. Discrimination Learning)

The total number of trials to criterion (maximum 30) for the two groups on this task is presented in Table 9. These parallel the scores in the first study where means of 22.8 and 22.0 for the frontal and temporal groups respectively were obtained. (The scores for four of the temporal lobe subjects are of course from the first study.) Table 10 shows the post-search error scores for the subjects

Table 9. Total number of trials to criterion (Discrimination Learning Task 1)

Subject Number	Frontal	Subject Number	Temporal
F11	30	T1	29
12	18	4	30
13	30	8	11
14	22	9	12
15	10	11	11
16	15		
17	16		
18	12		
19	22		
20	30		
Mean	20.5		18.6

Table 10. Overall post search errors as a percentage of the total number of trials to criterion (Discrimination Learning Task 1)

Subject Number	Frontal	Subject Number	Temporal
F11	57	T1	17
12	16	4	70
13	43	8	0
14	36	9	8
15	0	11	9
16	6		
17	19		
18	0		
19	23		
20	30		
Mean	23.0		20.8

expressed as a percentage of the total trials to criterion. (The raw data may be found in Appendix Q.) These do not compare quite so favourably with scores from the first study where means of 26.1 and 16.7 were obtained for the two groups. In fact, contrary to the results from the first study the two sets of scores in Table 10 were not found to differ significantly using the Mann Whitney U test ($p > 0.05$, one tailed). However the number of subjects in the temporal group is very small and, as examination of the data from the first study shows, one subject with an unusually high (70%) score was included.

Experiment 4. Serial Learning

The total number of items recalled in the correct position in the high and low distractibility conditions is shown in Table 11. From this it emerges that the number of items correct expressed as a percentage of the maximum possible number correct was 49% overall, which compares with 64% for the Gordon and Fenoulhet (1971) study. The lists in their experiment however contained 16 items suggesting that the difference may well have been even greater if lists of comparable length had been used in this experiment. Insofar as the subjects in Gordon and Fenoulhet's experiment (students at a College of Education) may be regarded as a "control" group therefore, these results suggest a general reduction in serial learning ability due to brain damage.

Table 11. Total number of items recalled in correct position in conditions of high and low distractibility. (Experiment 4. Serial Learning)

Subject Number	Frontal High	Frontal Low	Subject Number	Temporal High	Temporal Low
F11	18	24	T1	10	17
12	8	8	4	16	12
13	17	13	8	11	11
14	14	16	9	19	18
15	11	10	11	13	14
16	17	16			
17	21	24			
18	10	9			
19	16	18			
20	14	15			
Mean	14.6	15.6		13.8	14.4

The percentage of items recalled correctly can also be considered for the two conditions separately. In the Gordon and Fenoulhet study the relevant figures were 65% for the low distractibility condition and 62% for the high. In the present experiment the percentages were 50 and 48 taking the frontal and temporal groups together.

The number of items recalled correctly as a function of their serial position within the list is presented in Figure 7. Scores for the two groups are shown separately as percentages of the maximum possible. The distribution of scores appears to be more or less consistent with the typical serial position curve for normals with its "primacy" and "recency" effects.

In order to test the hypothesis that the performance of frontal lobe patients should be related to their post-search error scores, each frontal subject's score under the "high distractibility" condition was subtracted from the corresponding score under the "low distractibility" condition and the measures obtained were then correlated with the subjects' post-search error scores using Kendall's Tau. The prediction of the sensory disinhibition hypothesis is that the higher the post-search error score the greater the value of the difference should be. A positive correlation of 0.33 was obtained. Using the formula given by Siegel (1956), this value of Tau yielded a 'z' score of 1.33 which has an associated probability of 0.09 (one tailed test). Thus the prediction of the sensory disinhibition hypothesis was not borne out.

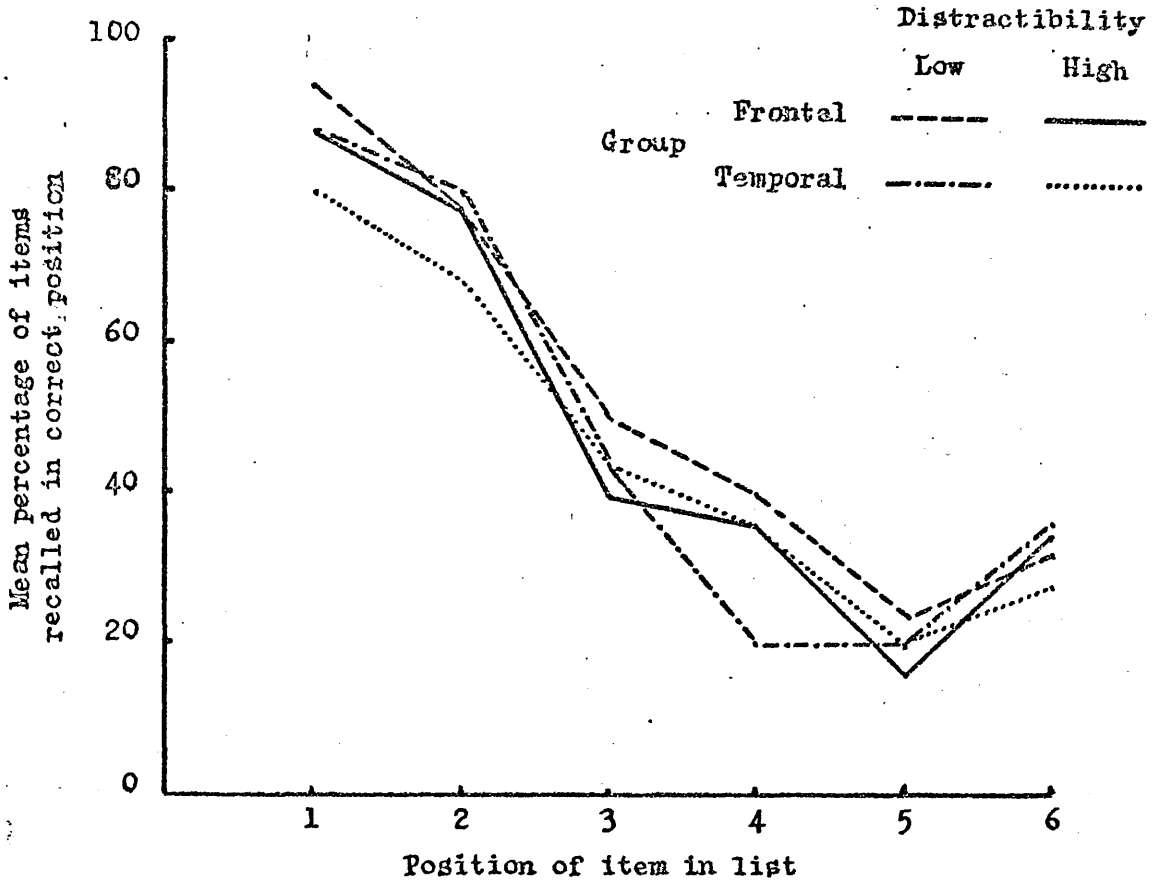

Figure 7. Mean percentage of items recalled in correct position under conditions of high and low distractibility. (Experiment 4. Serial Learning).

Inspection of the data however reveals that with the exception of one subject (F13) the general trend of results is in line with the prediction. In fact, if this subject's scores are left out of the analysis, the correlation rises to +0.62 ($z = 2.33$, $p = 0.01$, one tailed). If this subject is eliminated therefore, the results of the experiment do lend some support to the sensory disinhibition hypothesis.

The data obtained for the temporals were also subjected to analysis by correlation in the same way. A correlation of zero was obtained ($p = 0.59$). The performance of the small number of temporal lobe subjects therefore appears not to be related in any obvious way to their post-search error measures.

In order to determine whether there were any significant differences between the scores for the two groups of patients, the data presented in Table 11 were analysed using Analysis of Variance. (See Appendix K.) As inspection of the data might suggest, the F values for the main effects (Distractibility Conditions and Lesion group) and their interactions failed to reach significance ($F < 1$). The sensory disinhibition hypothesis of course predicts more disruption of performance in the "high distractibility" condition than the "low" for frontal subjects compared with temporals, but the lack of a significant condition x Lesion group interaction does not bear this out. In view of the significant positive correlation between post-search error scores and the

difference between recall in the two conditions reported earlier (ignoring scores for F13) this result is somewhat surprising and raises a number of questions which are considered in the Discussion.

Another aspect of the result concerns the requirement that the serial order of the items was to be retained. It may be inferred from the discussions presented by e.g. Luria (1966), Barbizet (1972) and Milner (1971) referred to earlier (Chapter 2) that although frontal lobe subjects do not suffer any reduction in memory capacity, they nevertheless should experience difficulty in storing (or recalling) information about the order in which a series of items were presented. This suggests that frontal patients in this experiment should have remembered the items correctly, but in the wrong order, more often than temporals. The relevant data are presented in Table 12 which shows the number of items which was correctly recalled when errors of position are ignored. It must be admitted that there are difficulties with this measure from a statistical point of view since subjects whose recall scores are relatively high will be more likely to have produced "correct" response (in the wrong position) by chance than those whose scores are relatively low. However even if the data in Table 12 are assumed to have some degree of validity, inspection of the figures suggests that they do not support the hypothesis of an impairment in memory for serial order in frontal subjects.

Table 12. Total number of items recalled correctly ignoring errors of position. (Experiment 4. Serial Learning)

Subject Number	Frontal High	Frontal Low	Subject Number	Temporal High	Temporal Low
F11	22	25	T1	16	21
12	19	21	4	20	17
13	21	18	8	17	16
14	19	21	9	24	24
15	13	11	11	18	16
16	25	25			
17	22	24			
18	16	16			
19	20	19			
20	16	19			
Mean	19.3	19.9		19.0	18.9

The results of the serial learning experiment therefore constitute only moderate support for the sensory disinhibition hypothesis. The performance of frontal lobe patients was found to be related, as predicted, to post-search errors measured in a separate task. In overall performance however the two groups are indistinguishable.

Experiment 5. Delayed Paired Comparisons

Subjects decision speeds under the various conditions are presented in Table 13. The scores for "familiar" and "novel" pairs are presented separately according to whether the correct response was "same" or "different". In addition the "familiar" scores are presented according to whether they represent readings from the first 10 trials ("pre-novel"), or were obtained during the second 16 trials, or "novel period", (i.e. trials 11-26), in which novel pairings also occurred. Decision speeds for trials on which novel stimuli were presented are shown according to the particular combination involved: novel-novel (N-N), familiar-novel (F-N), and novel-familiar (N-F). For "familiar" trials each subject's score is an average of six (there being six "different" and six "same" pairings), whereas in the novel trials the scores are from a single trial only.

Table 13. Decision speeds (milliseconds) in Experiment 5. (Delayed Paired Comparisons). The number of readings on which each entry is based is indicated at the head of each column.

		FAMILIAR PAIRS							NOVEL PAIRS					
		RESPONSE "SAME"			RESPONSE "DIFFERENT"				RESPONSE "SAME"	RESPONSE "DIFFERENT"				
		N=5	N=6	N=11	N=5	N=6	N=11		N=1	N=1	N=1	N=1	N=3	N=4
		Trials 1-10	Trials 11-26	Mean	Trials 1-10	Trials 11-26	Mean	Overall Mean	N-N	N-N	F-N	N-F	Mean	Overall Mean
FRONTAL	F11	0758	0843	0805	0718	1010	0879	0842	0877	0702	0936	1082	0907	0899
	12	0610	0816	0727	0980	0612	0779	0751	0789	1023	0497	0965	0828	0819
	13	1790	1230	1460	2080	2190	2146	1802	1609	1170	0936	1842	1316	1389
	14	1040	0916	0978	1130	0775	0940	0958	1023	0760	0994	0848	0867	0906
	15	0964	0945	0954	1040	0657	0830	0892	1491	0936	0789	1520	1082	1184
	16	1103	0740	0886	0634	0862	0758	0819	0760	0819	0848	0848	0838	0819
	17	1700	1980	1830	1690	1900	1807	1816	2164	2368	1754	1871	1998	2039
	18	1162	1002	1082	1298	1168	1226	1158	2193	0643	0840	0906	0796	1146
	19	1628	0882	1221	0996	1100	1053	1137	1671	1968	1394	1673	1678	1677
	20	1784	1319	1530	1248	1180	1211	1370	1374	1032	1004	1545	1194	1239
	Mean	1254	1067	1147	Mean 1181	1145	1163	1155	Mean 1395	1142	0999	1310	1150	1212
TEMPORAL	T1	0877	1162	1055	0976	0910	0935	0988	1400	0992	1224	2024	1413	1410
	4	1670	1731	1703	1898	1985	1945	1824	0880	1203	1030	1217	1150	1083
	8	1448	0952	1150	1316	1047	1169	1083	1010	1156	1176	1218	1183	1140
	9	1008	0807	0898	0744	0688	0716	0811	0930	1310	1120	1090	1173	1113
	11	0644	0690	0669	0966	1038	1005	0837	0820	1012	1970	0780	0917	0893
	Mean	1129	1068	1095	Mean 1180	1134	1154	1109	Mean 1008	1135	1304	1266	1167	1128

In order to test the hypothesis that the effect of novel stimuli on frontal lobe patients' performance is related to their post-search error scores, the averages of the subjects' response times to the three "different" trials on which novel stimuli occurred were subtracted from the average scores for the six familiar "different" pairs obtained during the "novel" period (i.e. column 12 scores minus column 5 scores). These measures were then correlated with the subjects' post-search error scores using Spearman's Rank Correlation. A value of rho -0.30 ($p > 0.05$) was obtained for the novel "different" trials correlation and of -0.25 ($p > 0.05$) for novel "same" trials. These results do not confirm the predictions of the sensory disinhibition hypothesis. In fact even the sign of the correlations (negative in both cases) is contrary to what is predicted since what this seems to suggest is a reduction in the effect of novelty with increases in sensory disinhibition measured according to post-search error rates.[1]

In Table 14 scores for the "novel" period only (i.e. Trials 11-26) are presented. These scores were selected as

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[1] The most straightforward interpretation of the sensory disinhibition hypothesis is of an impairment of performance in the presence of novel stimuli. Given a relatively monotonous experimental task such as this one however there may perhaps be an argument for predicting an improvement (see also p. 50).

Table 14. Decision Speeds (milliseconds) obtained during second part (i.e. Trials 11-26) of Experiment 5. (Delayed Paired Comparisons)

		Familiar Pairs		Novel Pairs	
	Subject Number	N=6 Same	N=6 Different	N=1 Same	N=3 Different
FRONTALS	F11	843	1010	877	907
	12	816	612	789	828
	13	1230	2190	1609	1316
	14	916	775	1023	867
	15	945	657	1491	1082
	16	740	862	760	838
	17	1980	1900	2164	1998
	18	1002	1168	2193	796
	19	882	1100	1671	1678
	20	1319	1180	1374	1194
Mean		1067.3	1145.4	1395.1	1150.4
TEMPORALS	T1	1162	910	1400	1413
	4	1731	1985	880	1150
	8	952	1047	1010	1183
	9	807	688	930	1173
	11	690	1038	820	917
Mean		1068.5	1133.6	1008	1167.2

the most appropriate for comparison purposes since they were obtained during the same part of the experiment. After converting these data to reciprocals, a Nested Analysis of Variance was carried out. A summary table of this may be found in Appendix L. None of the F values obtained reached significance.

By way of summary it may be said that the data obtained in this experiment do not bear out the expectation that the frontal lobe subjects' hypothesized sensitivity to novel stimuli would produce an impairment of performance. What was taken in the first study as a measure of the subjects' distractibility was not related in any systematic fashion to behaviour which occurred in the presence of apparently novel stimuli nor did the performance of frontal lobe patients differ in any respect from temporals.

Experiment 6. Conflicting Stimuli

The results of this experiment are presented in Table 15. In this table the means are based on 10 readings. (The raw data are to be found in Appendix R.)

In order to determine the relationship between the subjects' performance under the three conditions and the post-search error scores which had been obtained,

the following measure was derived: the discrepancy between each subject's observed scores within condition 2 and within condition 3 from the predicted scores, given the regression of that condition's observed scores upon those of condition 1. These "discrepancy scores" (presented in Appendix M (i)) were then correlated separately for each condition with the post-search error measures using Spearman's Rank Correlation.

Table 15. Mean Decision Speeds (milliseconds) in the three conditions of the Experiment 6. (Conflicting Stimuli)

	Subject Number	Condition 1	Condition 2	Condition 3
FRONTALS	F11	392	368	495
	12	487	503	632
	13	576	576	576
	14	609	587	599
	15	704	590	571
	16	414	421	373
	17	1013	931	985
	18	634	626	577
	19	519	559	468
	20	447	533	399
	Mean	579.5	569.4	567.5
TEMPORALS	T1	673	599	468
	4	635	842	684
	8	699	541	623
	9	477	386	617
	11	412	483	430
	Mean	579.2	570.2	565.4

A value of +0.37 was obtained for the correlation between Condition 2 discrepancy scores and post-search errors. This is not significant ($p > 0.05$). In the case of the correlation between Condition 3 discrepancy scores and post-search error scores, a value of rho of −0.06 was found. This is also insignificant ($p > 0.05$). A similar analysis of the temporal lobe group's scores did not reveal any significant correlations.

A less satisfactory form of analysis does suggest the possibility that, with increases in post-search errors, there may be a corresponding tendency for decision times in condition 3 to be lengthened in comparison with condition 1. When the raw scores in conditions 2 and 3 were each subtracted from the appropriate scores in condition 1 and correlated separately with the post-search error measures, values of rho of +0.20 and −0.62 respectively were found. This latter correlation is highly significant ($t = 3.61$, $p < 0.01 > 0.02$, two tailed). This method of analysis is unsatisfactory since, for example, condition 3 minus condition 1 scores are necessarily correlated with those for condition 2 minus condition 1. Further, either of these differences reflects differences in variability as well as differences in mean level; in other words, the range of possible variation for a given subject, his scores in either condition 2 or 3 having been subtracted from those of condition 1, may depend almost entirely on his scores in condition 1. If this were the case, the presence or absence of any correlation would also reflect largely the influence of condition 1, and not, as intended, that of condition 2 or 3.

After converting the scores in Table 15 to reciprocals, the data were subjected to a Nested Analysis of Variance. It may be predicted that if frontal lobe patients experience difficulties in selective attention even in the absence of novel forms of stimuli, there should be an overall effect due to Lesion group. Moreover, if one of the characteristics of this attention deficit stems from an inability to avoid processing information which has been defined as "irrelevant", the performance of frontals can be expected to be affected more by Condition 2 than 3 compared with temporals since the "irrelevant" stimuli in Condition 2 are potentially relevant to the response.

A summary table of the Analysis of Variance is provided in Appendix M but neither the main effects (Lesion group and Irrelevant Stimuli conditions) nor interactions were significant ($F < 1$). This may be compared with the results of the serial learning experiment where no significant Lesion group x Conditions interaction was found, in spite of a significant correlation within the frontal lobe group.

The results of the conflicting stimuli experiment therefore do not really provide much support for the sensory disinhibition hypothesis. The performance of the frontal lobe subjects appears to be indistinguishable from the temporals and such correlations as were found between various measures of performance within the frontal lobe group do not appear to have any immediately obvious significance for the sensory disinhibition hypothesis.

Discussion

Experiment 4. Serial Learning

There was no evidence in this experiment of any overall differences in short-term retention in the two brain-lesioned groups. While it would be unwise to draw too many conclusions from a study involving such relatively small numbers of subjects this suggests to begin with that frontal lobe patients do not suffer any reduction in learning capacity arising out of an inability to cope with the serial structure of lists of items. Testing at longer retention intervals may reveal differences however so the hypothesis should not be discounted purely on the basis of this experiment.

As far as the sensory disinhibition hypothesis is concerned perhaps the most important finding is the significant correlation between the frontal lobe subjects' "post-search error" measures and the difference between their recall scores under the low and high distractibility conditions, providing that the scores of one subject (F13) are discarded. This suggests that subjects who are regarded as relatively more distractible in one experimental situation (discrimination learning) are more affected by variability of input in another (serial learning) when compared with subjects whose distractibility scores (post-search errors) are relatively low. This is consistent with the sensory disinhibition hypothesis and also extends the usefulness of the post-search error score as a measure of frontal lobe subjects' behaviour. The result would not

be predicted from Milner's (1971) "difficulty in switching" hypothesis since this makes no reference to the importance of stimulus variables such as novelty. As with experiments 1-3 however, there is a difficulty in deciding how far "novelty" may be distinguished from "variability". Letters are arguably stimuli of great familiarity, even when they are read out individually. This suggests that it may be possible to distract frontal lobe patients with a small number of familiar stimuli, providing that these are presented (as they were in this experiment) in a way which makes it difficult for subjects to avoid them.

It is of some interest that the post-search error measures obtained in this experiment do not enable one to distinguish between frontals as a whole from temporals in terms of their overall scores. One possibility is that the effect which sensory disinhibition has on the behaviour of frontal patients is analogous to the effect of a drug or other type of treatment. For example, the provision of additional vitamins will benefit an individual's health only if vitamin deficiencies are present. Similarly, variations of sensory input may only affect the performance of frontal lobe patients if they are susceptible to distraction (i.e. if their post-search error scores are relatively high). One implication of this is that temporals should have a reduced capacity for serial learning <u>per se</u> in comparison with frontals, so that what, as it were, brings down the performance of the frontal group to the level of the temporals is the former's susceptibility

to sensory disinhibition. As the review of the literature in Chapters 1 and 2 suggests, however, it is frontal rather than temporal lobe lesions which have more often been associated with "short-term" learning deficits.

There was no significant correlation between post-search errors and recall scores in the temporal lobe group. Although the number of subjects in this group was very small, this suggests that, possibly, differences in the post-search error scores of temporals do not reflect differences in sensory disinhibition; or, alternatively, that the susceptibility of temporals to distraction is not great enough to be of any significance in this serial learning experiment. In fact there was some evidence in the original discrimination learning experiment (Experiment 1) that the post-search error scores of the temporal lobe group were higher in Task 2 than Task 1 in contrast to the frontals whose scores were higher under the conditions of greater distractibility exemplified by Task 1. (The task used in these follow-up experiments was Task 1.) This suggests that the relationship between the "post-search error" and "sensory disinhibition" in temporals is possibly less straightforward than for frontals. The situation might be clarified if Task 2 had been administered in this series of experiments as well.

On the whole therefore, the results of the serial learning experiment provide limited support for the sensory disinhibition hypothesis. There is evidence that the "distractibility" of frontal lobe subjects is related to

their ability to cope with variations of irrelevant input when submitting lists of items to memory, even though the performance of the frontal group as a whole does not differ from the small group of temporals.

Experiment 5. Delayed Paired Comparisons

The results of this experiment did not provide any support for the sensory disinhibition hypothesis. Frontal lobe patients did not differ from temporals in response to the various novel stimuli, nor was there any evidence of a relationship between the frontal subjects' performance and their "distractibility" (post-search error) scores. Moreover, insofar as the experimental situations can be treated as comparable, these results do not parallel those of Prisko (1963) who found a deficit in frontal lobe patients on similar tasks of delayed paired comparison. Nor was there any suggestion, taking both groups together, that "same-same" judgements were faster than "same-different" judgements, contrary to the situation observed in normal subjects (e.g. Posner and Mitchell, 1967).

The aim of the experiment was to examine how the performance of frontal lobe subjects would be affected by the presentation, without warning, of a number of "novel" stimuli. It was thought that this would perhaps provide a more appropriate test of the hypothesized increased sensitivity of frontals to novelty than the discrimination

learning experiment (Experiment 1) because (a) in the present experiment only a small number of such stimuli was involved and (b) the subjects did know about them in advance. However, this procedure failed to elicit any significant effect and it would seem therefore that frontal lobe patients are not unduly responsive to novel forms of stimuli, or at least that their behaviour is not disrupted by them in the way that Buffery (1964) observed for baboons. Possibly there are "novel" stimuli which might have had such an effect in this experiment but it is difficult to imagine what these might be. Another possibility is that even though the performance of frontal lobe subjects does not appear to be impaired by novel stimuli, such patients may notice them more readily than control subjects. This might be tested by presenting subjects with a number of objects and requiring them to pick the "odd man out" as in, for example, Harlow's "oddity learning" experiments, or possibly by some test of incidental learning.

It must be remembered also however that in Buffery's discrimination learning experiments, the distracting stimuli were presented on the day after learning to criterion had taken place. Such a long interval was not envisaged in any of the experiments reported here, for obvious practical reasons, but it remains a possibility that if a similar procedure were adopted a comparable deficit might emerge. The main problem would seem to be in selecting stimuli which are complex enough to be considered "novel" (and which

do not easily lend themselves to the use of a verbal coding strategy) while at the same time ensuring that they are not so different from each other as to make the discrimination too simple.

However the conclusion as a whole must be that on the results of this delayed paired comparison experiment there is no reason to suppose that patients with frontal lobe lesions are unusually sensitive to novel stimuli and in this respect there is no support for the sensory disinhibition hypothesis. In fact it might be argued that even those experiments reported earlier, which appeared to provide evidence for a link between frontal lobe damage and an increase in sensitivity to novelty, do not really do so. That is to say although the results of, for example, the serial learning experiment seem to provide a modicum of support for the idea, the critical factor in this experiment was, arguably, the variability rather than the novelty of the irrelevant stimuli, which were always just ordinary letters. This of course raises a number of points, such as how novelty should be defined, which are discussed later.

Experiment 6. Conflicting Stimuli

This experiment suggested that as the post-search error scores of the frontal lobe group increased there was no significant tendency for decision times in Condition 3 to be lengthened in comparison with Condition 1. The same relationship was also found for post-search errors and scores

in Condition 2, and no significant correlations emerged from the analysis of the temporal lobe subjects scores. In addition there was no evidence of any overall differences between the two groups of patients in all three conditions.

There are several aspects of these results which require comment from the point of view of the sensory disinhibition hypothesis. First of all the fact that there were no overall differences in the performance of the two groups does not parallel the results of Buffery's (1964) matching from sample experiments in which frontal baboons were found to have longer response latencies than temporals. The number of temporal lobe patients in the present study was of course very small and the experimental situations not directly comparable but, as far as this result goes, it seems that frontal lobe injury in man does not produce a difficulty at the "registration" stage. In addition to this, if frontal lobe patients are more likely to "process" irrelevant stimuli than temporals then frontals should have experienced greater difficulty in Condition 2 than Condition 3 since the "to-be-ignored" stimuli in Condition 2 were in fact potentially relevant to the response. However no such Task x Lesion group interaction was found.

In relation to conditions 2 and 3, the sensory disinhibition hypothesis need not necessarily be interpreted as leading to the predictions outlined earlier. Strictly speaking, the sensory

disinhibition hypothesis predicts an impairment of performance under any conditions of distraction. This means that if post-search errors do provide a measure of a subject's susceptibility to distraction there is no reason why these scores should not be related in the way that they are to the increase in response times in Condition 3 (i.e. when 'c' is present on the "irrelevant" side of the card).[1] On the other hand a comparable correlation should presumably also be found for scores in Condition 2 in which the letter 'b' occurred on the "irrelevant" side. Moreover in view of the fact that frontals were expected to be more affected by Condition 2 than Condition 3 it might be argued that this correlation should be even greater in Condition 2. It is possible that such a result would not be as difficult to reconcile with the sensory disinhibition hypothesis as might be thought. For example it could be argued that the discrepancy does reflect the greater susceptibility of subjects with high post-search error scores to distraction by "novel" stimuli, if novel is defined as "non-task relevant". That is to say frontal lobe subjects may have no difficulty in restricting attention to the "relevant" side of the card as long as only task relevant information appears on the other side. However once something appears for which there is no available response within the context of the task the frontal patient experiences difficulty and the effect is related to the subject's distractibility score. However this does seem to go against the spirit of the

[1] In fact when the data in question were analyzed in terms of raw differences, there was a strong suggestion of a relationship of this kind. However, for reasons explained on page 142, this method of analysis is statistically unsatisfactory.

sensory disinhibition hypothesis which stresses the importance of complex novel stimuli in the attention deficit. On the other hand in view of the failure of earlier experiments to implicate novel stimuli specifically, there may be grounds for believing that if frontal lobe damage does produce an impairment of attention in man, it may not necessarily take the same form as envisaged by the sensory disinhibition hypothesis.

On the whole, therefore, the results of the conflicting stimuli experiment cannot really be regarded as constituting more than moderate support for the sensory disinhibition hypothesis. Frontal lobe subjects and temporals did not differ from each other in their overall response times and although there may be a relationship between the distractibility of frontals and their reaction to certain forms of irrelevant stimuli, the significance of this is not immediately clear.

Concluding Remarks

In these experiments subjects with frontal and temporal lobe damage have been compared with each other, and in some cases with a group of control subjects, on a range of cognitive tasks concerned with selective attention. From the results of these it may be concluded with confidence that brain damage itself exerts a detrimental effect on performance. However there is only moderate evidence of a selective impairment due to locus of lesion.[1] The results as a whole, therefore, do not inspire a great deal of confidence in the value of the "sensory disinhibition" hypothesis as an explanation of the effects of frontal lobe damage in man. A number of points must be considered however before the hypothesis can be rejected.

To begin with, it is difficult to see how any of the alternative hypotheses concerning frontal function, discussed in Chapter Two, could account for the significant results obtained in these experiments. The differences between frontals and temporals, in terms of post search errors and alternations, and the relationship between post-search errors in the frontal group and their performance on other tasks do not accord well with an interpretation in terms of a reduction in intelligence, a memory or perceptual

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[1] One encouraging aspect of the results of the discrimination learning experiments is the suggestion that measurement of the pattern or sequence of responses may sometimes be more informative than the more traditional count of the number of errors or total trials to criterion.

deficit, or a disturbance in the regulation of behaviour. It must also be remembered that the sensory disinhibition hypothesis was derived, in the main, from experiments conducted with animals, such as rhesus monkeys, which have received extensive bilateral lesions and which have been tested, generally, within a few weeks or months of surgery. The hypothesis was actually tested, and vindicated, by Buffery (1964) in relation to the performance of groups of baboons. The experiments described in this report, however, were carried out on patients with circumscribed lesions which, in most cases, were unilateral. It is possible therefore that the sensory disinhibition hypothesis could provide the basis for an explanation of the frontal lobe deficits, (a) in the acute stages and (b) especially where there has been considerable bilateral damage. The number of bilateral cases was too small for a separate analysis to be carried out on such patients as a special group. Only two really acute cases were tested in these experiments and their results were not included in the main analysis for reasons described earlier. Clinically however both these patients gave the often reported impression of being highly distractible and unable to maintain effective concentration. In addition to this there is the impression, referred to earlier, that many patients appeared, clinically, to fall into one of two categories: they seemed either to be relatively severely impaired or to have gained some insight into their condition and learned to cope with their difficulties. This suggests that appropriately selected subjects may be more suitable for testing the sensory disinhibition hypothesis than the more random sample used here.

The central argument of the sensory disinhibition hypothesis is that frontal lobe lesions render the organism more susceptible to distraction by extraneous stimuli, especially if these are unusual or novel. Thus the difficulty is essentially one of selective attention. Another point to be considered, therefore, is that frontal lobe damage in man does produce an attention deficit but that this may not necessarily have the same characteristics as have been observed by, for example, Buffery (1964), in baboons. That is to say, a deficit of selective attention may well result from damage to the frontal areas but the form which this takes may not be most accurately expressed in terms of "sensory disinhibition". It is possible, for example, that the ability to <u>divide</u> attention is impaired in some way, as suggested by e.g. Costello (1956), and that this is unconnected with the presence or absence of novel stimuli. Studies of dichotic listening might therefore be of some value. Another possibility is that the notion of sensory disinhibition could be retained without any particular priority being given to the importance of novel cues in producing the deficit. In fact, from a phylogenetic point of view, there may be grounds for expecting a less dramatic response to novelty in man compared with other primates. Certainly, ontogenetically, the notorious distractibility of young children is eventually brought under control with increasing maturity.

On the other hand it is still possible, of course, that frontal lobe patients are more susceptible to distraction by novel stimuli and that what needs to be done is for an

effective form of novelty to be found. Studies of "cross-modality" forms of extraneous stimulation might be informative since there was little indication in these experiments that the "novel" stimuli employed had any markedly disruptive effect. In fact, these considerations raise a number of questions concerning how both "novelty" and "sensory disinhibition" should be defined and measured. It is true, for example, that frontal subjects produced a significantly greater number of "post-search errors" and "alternations" in the discrimination learning problem in which the irrelevant discriminanda were regularly changed. However, although consistent with the sensory disinhibition hypothesis, these results might not necessarily have had much to do with the effects of "novelty" in any normally accepted sense of the term. It may be, for example, that as part of his strategy, the subject does not simply look for the rewarded stimulus but, for some reason, examines each card in turn to see if it was present on the previous trial. Finding that this is not the case may have a more disturbing effect on the performance of frontals than temporals. On this hypothesis the frontal-temporal difference in post-search errors would represent not so much the former's heightened sensitivity to novel cues ("disinhibition") as a relatively greater tendency for these subjects to behave impulsively in situations where changes occur which they do not understand. (The correlations between post-search errors and performance found in two of the follow-up experiments for the frontal group, however, do not accord

very well with this interpretation and remain something of a puzzle.) Another question concerns how "novelty" should be measured. On one argument any stimulus which is different from the one which preceded it is novel. It would seem, however, that more than this is needed for a "sensorily disinhibited" organism to be affected. The small coloured plastic toys used by Buffery (1964) with baboons suggest that, in this context at least, two things are important: the stimuli should (i) be complex (i.e. show sizeable variations along dimensions such as shape and colour), and (ii) be unfamiliar to the subject. What is "novel" for one species, however, may not be so for another and there are no real grounds for expecting that the use of equivalent stimuli in these experiments would have led to comparable effects. (The delayed paired comparisons experiment to some extent bears this out.) What is regarded as novel in human society probably does not rely to the same extent on what Bruner (1966) refers to as such "ikonic" (i.e. surface, sensory) features of objects but may instead depend upon the perception of "higher-order" features such as incongruity. The use of some form of "incongruous figures" such as those designed by Berlyne (1957), might therefore provide an alternative form of "distracting" stimulus for human subjects.

If these arguments seem captious, it must be remembered that, taken as a whole, none of the experiments described here suggested an undue degree of sensitivity to novelty in the frontal group. In conclusion, therefore,

these investigations into the effects of frontal lobe lesions in man provide only limited support for the sensory disinhibition hypothesis advanced by Buffery (1964) following work on baboons. However, as has been suggested, it is possible that the hypothesis, or some modification of it, could provide the basis for an explanation if the important variables involved in the disturbances in attention can be specified more precisely.

Glossary of terms (with reference to this thesis)

Attention: the selective responsiveness to specific sensory messages, with the simultaneous disregard of others.

Sensory Disinhibition: a disturbance of attention resulting in an abnormal tendency to respond unnecessarily to certain stimuli.

Perseveration: an abnormal persistence of response to any particular stimulus.

Distractibility: the tendency to respond to irrelevant stimuli, enhanced if these stimuli are novel.

Novelty: that quality of stimuli which are unfamiliar within their context, or which are non-task relevant.

Appendices

Appendix A
Frontal Lobe Group Details

Patient		Sex	Handedness	Occupation	Type of Lesion	Side of Lesion	Age	Period since operation
F1	J.D.	M	R	Army Instructor	Meningioma	R	35	6m.
F2	D.G.	M	R	Lorry Driver	Astrocytoma	L	33	1y.3m.
F3	M.H.	F	R	Housewife	Meningioma	Bilateral	56	2y.10m.
F4	E.R.	F	R	Housewife	Meningioma	R	57	11y.7m.
F5	S.B.	M	R	Council Administrative Officer	Meningioma	Bilateral	61	2y.8m.
F6	W.B.	F	R	Housewife	Meningioma	Bilateral	45	1y.8m.
F7	D.N.	F	R	Dressmaker	Meningioma	L	60	2y.4m.
F8	M.B.	F	R	Saleswoman	Meningioma	L	64	11y.
F9	B.H.	F	R	Housewife	Astrocytoma	L	43	6m.
F10	F.D.	M	R	Foreman	Meningioma	R	59	6y.6m.
F11	A.M.	M	R	Clerk	Meningioma	L	57	10y.
F12	I.N.	F	R	Housewife	Glioblastoma	L	58	1y.10m.
F13	E.S.	F	R	Housewife	Meningioma	Bilateral	65	3y.10m.
F14	E.S.	F	R	Factory Worker	Oligodendroglioma	L	48	2y.3m.
F15	A.M.	F	R	Housewife	Oligodendroglioma	R	54	3y.1m.
F16	B.V.	F	R	Nursery School Worker	Meningioma	L	45	1y.4m.
F17	C.S.	M	R	Factory Worker	Oligodendroglioma	L	52	2y.6m.
F18	D.M.	M	R	Computer Programmer	Meningioma	R	34	4y.6m.
F19	G.P.	M	R	Labourer	Astrocytoma	R	44	8y.10m.
F20	M.C.	F	R	Housewife	Meningioma	R	62	6m.

Appendix A (continued)
Temporal Lobe Group Details

Patient		Sex	Handedness	Occupation	Type of Lesion	Side of Lesion	Age	Period since operation
T1	S.J.	F	L	Teacher	Astrocytoma	R	28	5y.7m.
T2	W.S.	M	R	Carpenter	Astrocytoma	R	43	9y.2m.
T3	J.B.	F	R	Housewife	Glioblastoma	L	43	4y.8m.
T4	O.D.	M	R	Clerk	Choleostatoma	R	53	1y.3m.
T5	J.B.	M	R	Tractor Driver	Intracerebral Haematoma	L	51	6y.10m.
T6	M.R.	F	R	Housewife	Intracerebral Haematoma, Astrocytoma	L	50	3y.7m.
T7	M.I.	M	R	Electrician	Abscess	L	19	9y.10m.
T8	M.W.	F	R	Housewife	Astrocytoma	R	49	3y.5m.
T9	G.S.	M	R	Tug Captain	Astrocytoma	L	61	7m.
T10	R.A.	M	R	Marine Engineer	Temporal Lobe Epilepsy (Lobectomy)	L	44	3y.8m.
T11	P.C.	F	R	Housewife	Meningioma	R	32	1y.

Appendix A (continued)
Control Group Details
(prolapsed intervertebral discs)

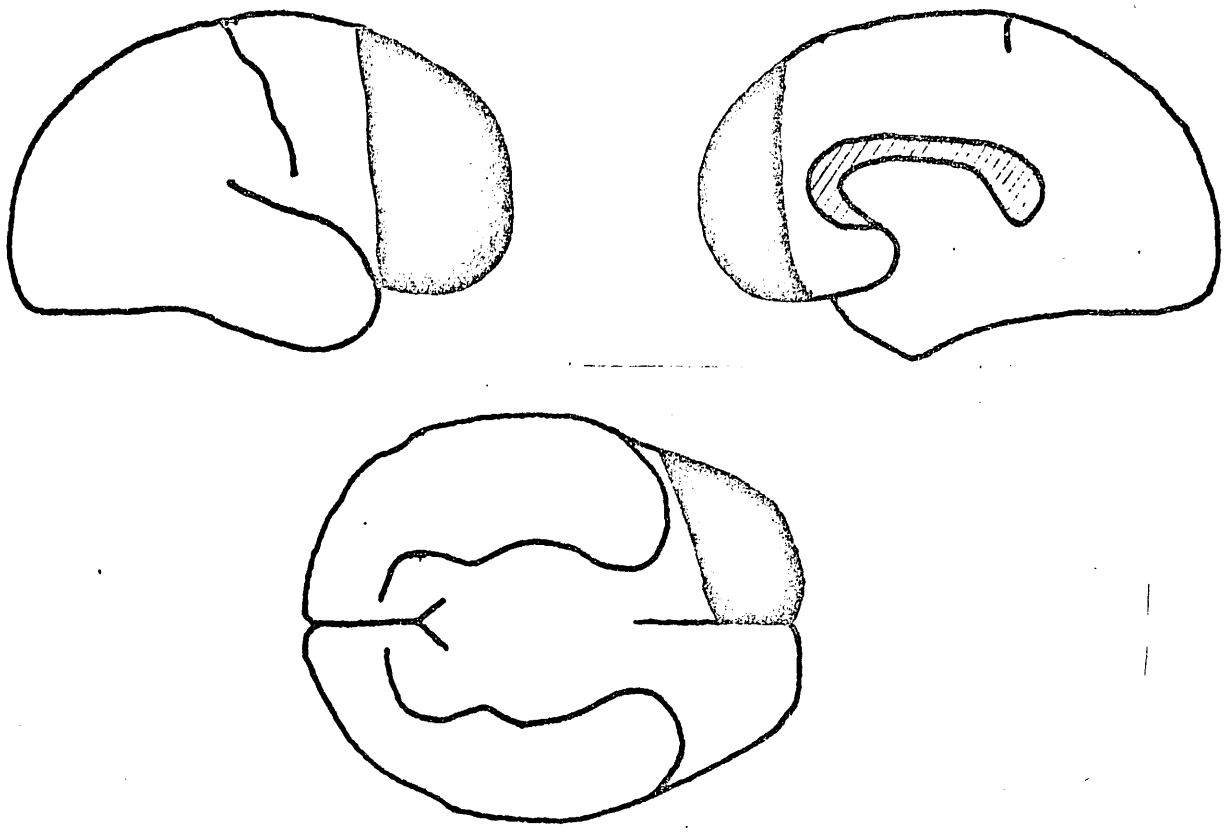
Patient		Handedness	Occupation	Age
C1	S.C.	R	Bank Messenger	31
C2	D.A.	L	Clerk	36
C3	M.S.	R	Housewife	36
C4	D.C.	R	Broker	39
C5	B.G.	R	Accounts Manager	40
C6	D.G.	R	Machine Service Worker	41
C7	R.H.	R	Foreman	41
C8	P.B.	R	Part-time Teacher	52
C9	W.L.	L	Hospital Porter	54
C10	D.F.	R	Housewife	52

There is a greater proportion of younger subjects in this group than in the brain lesion groups. Two factors may have contributed to this: (i) the relatively greater age at which brain tumours typically develop in comparison with cases requiring spinal surgery of this type; (ii) the unwillingness of older control subjects to participate, due to a relatively greater reduction in physical mobility.

It is not thought that such differences in age made any significant contribution to the results

Appendix B

Surgeon's reconstructions of the locus and extent of the lesions received by the frontal and temporal lobe groups. Lateral, mesial and basal surfaces are shown where appropriate.



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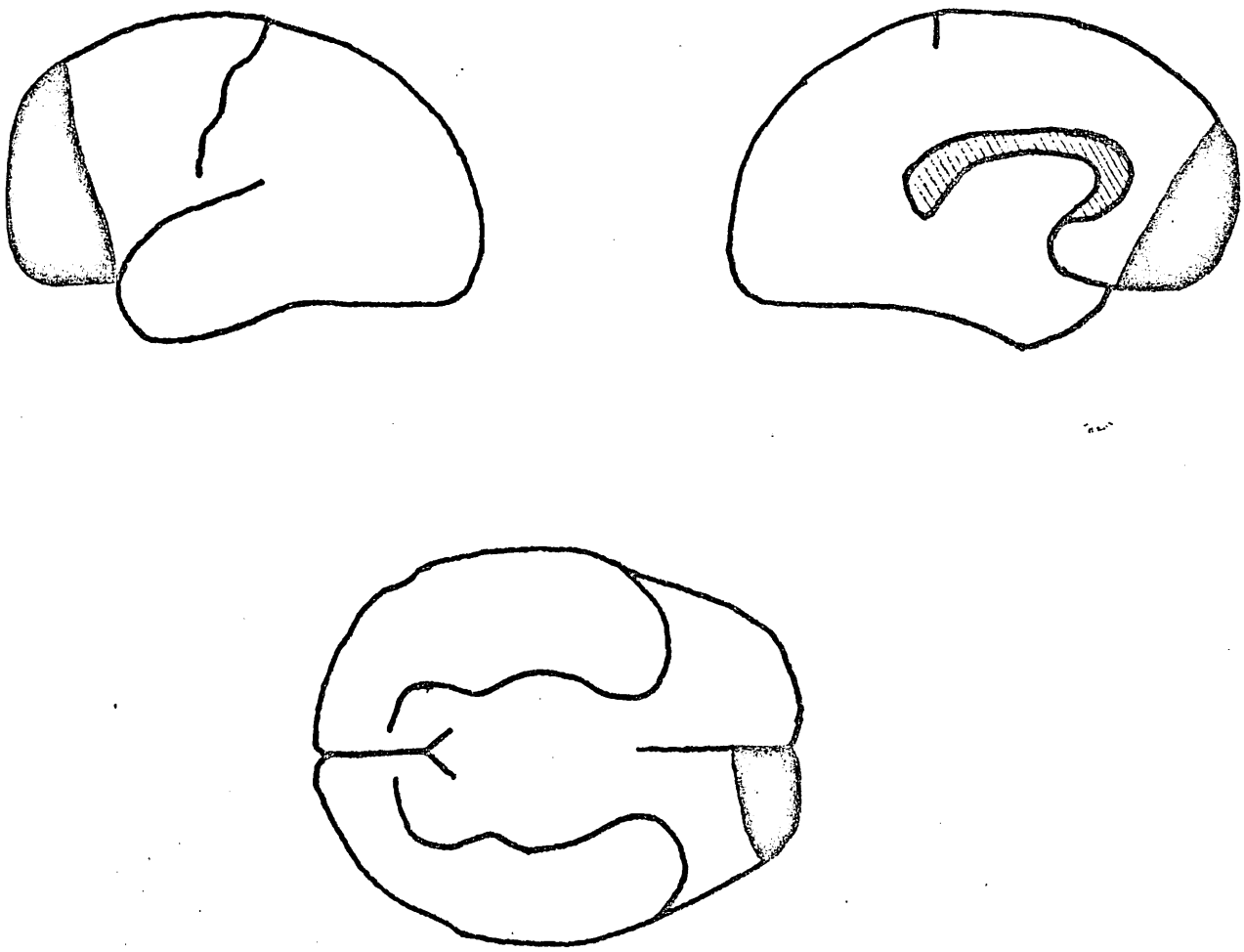

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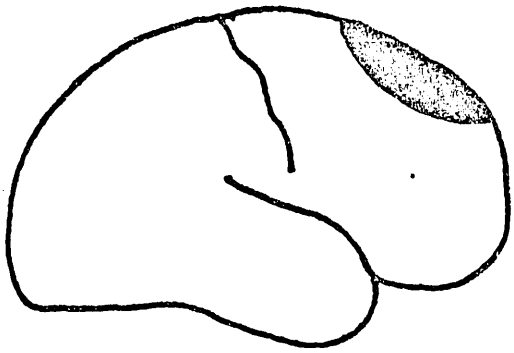
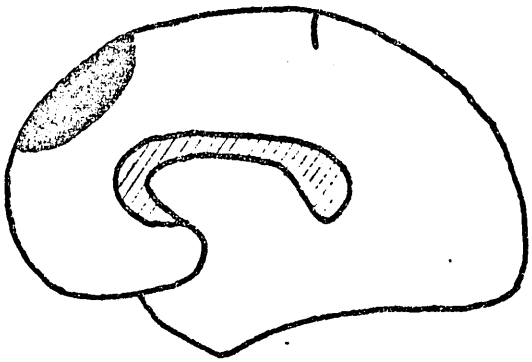
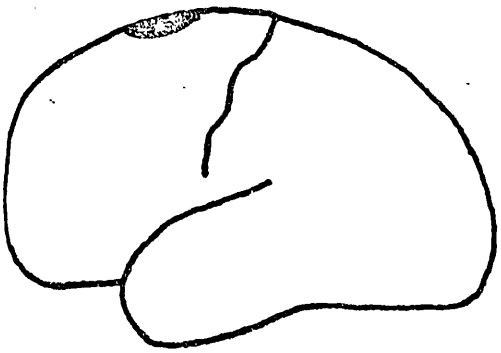
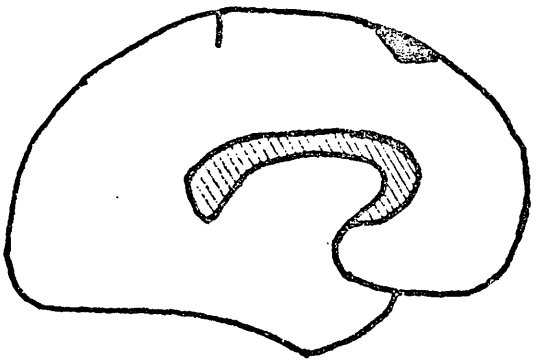
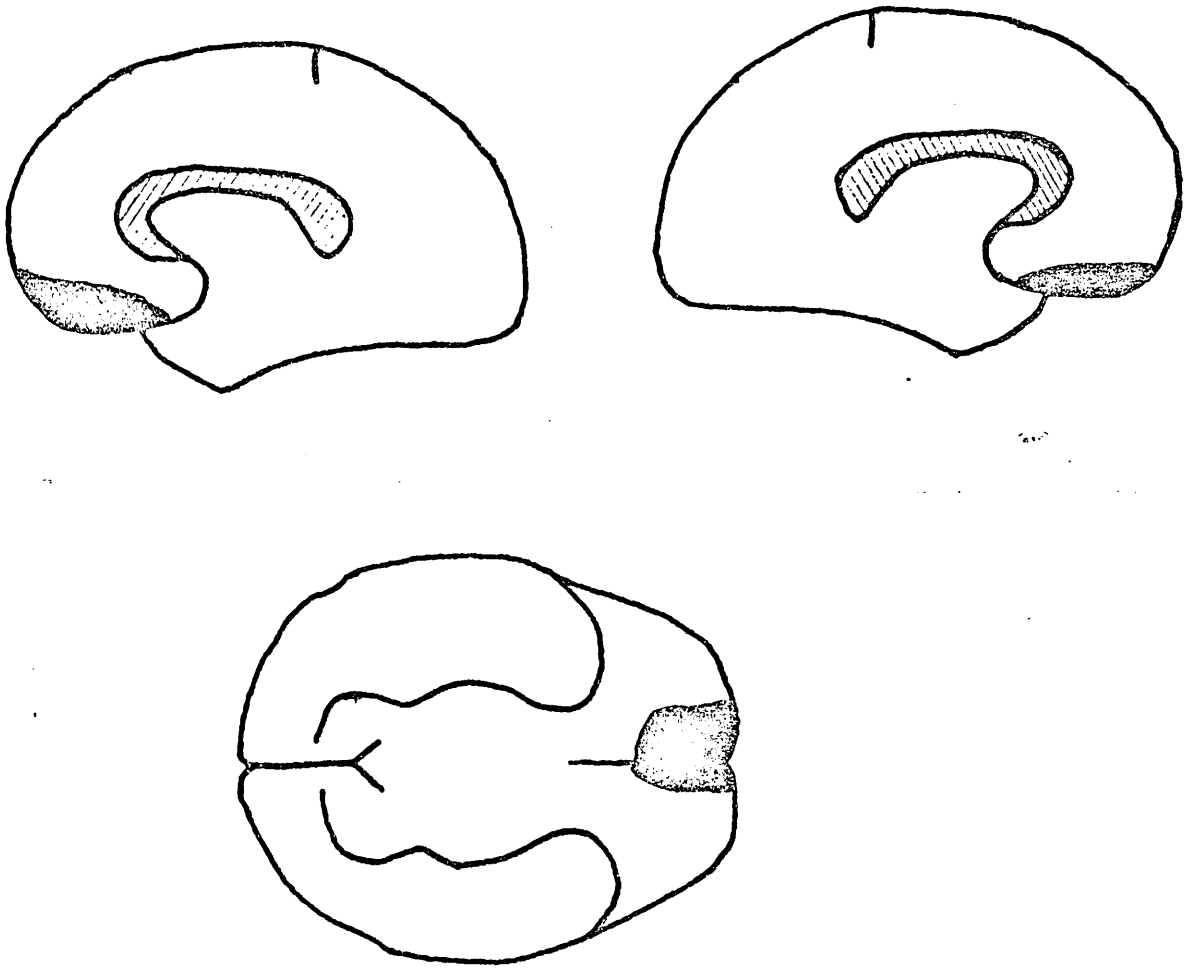




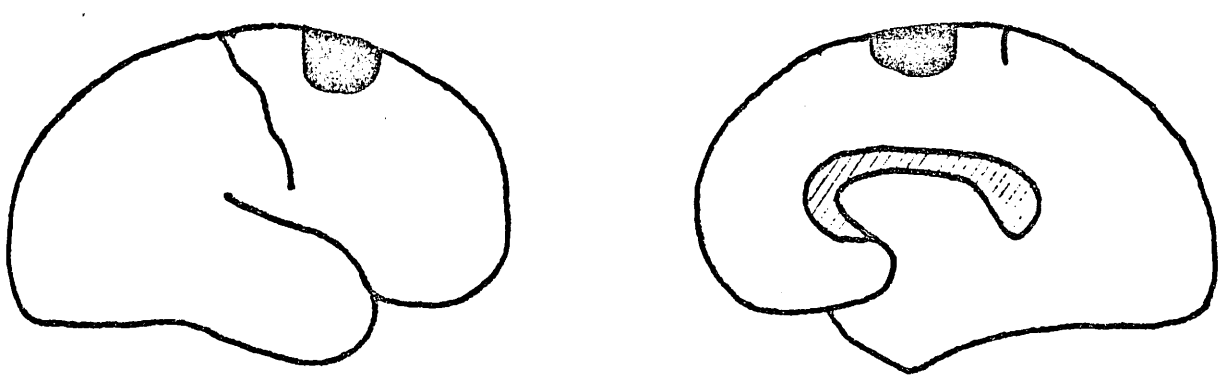




F3 M.H.



F5 S.B.



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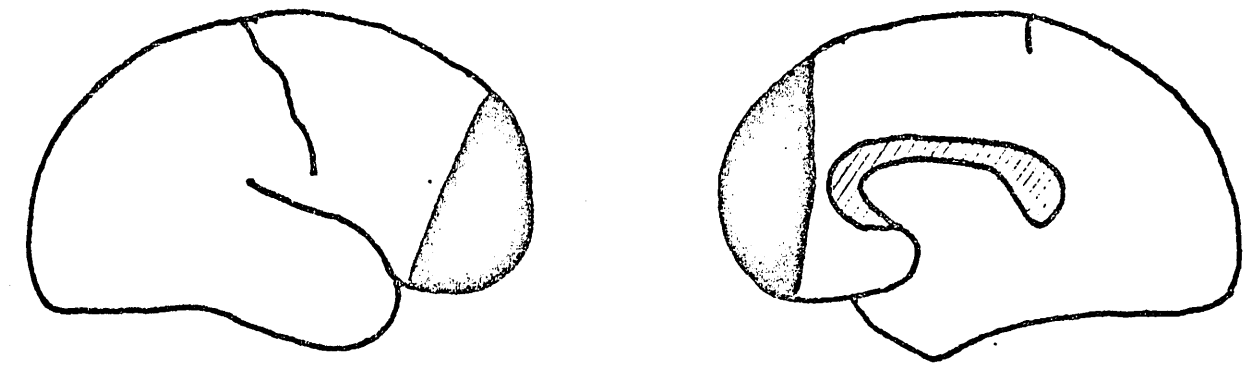
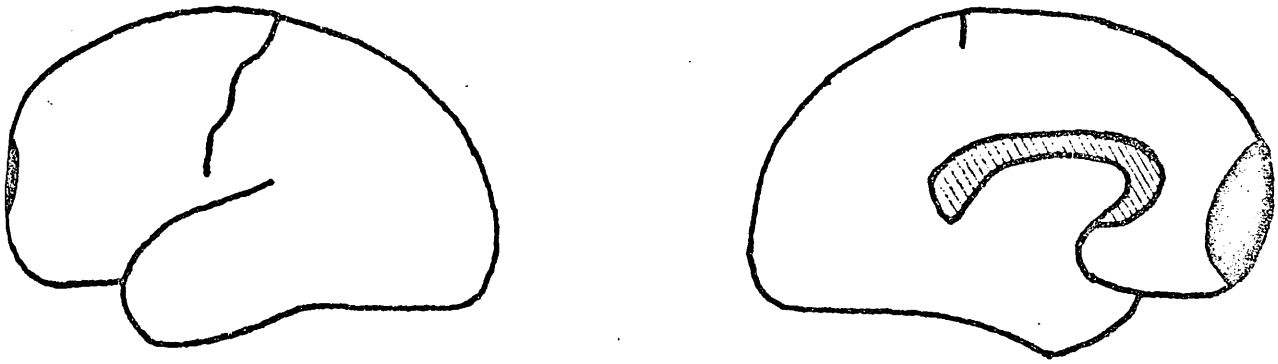
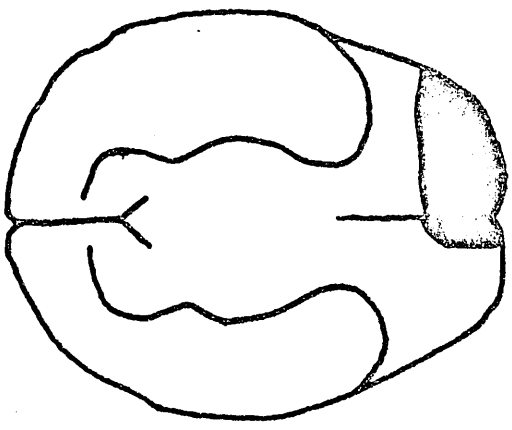
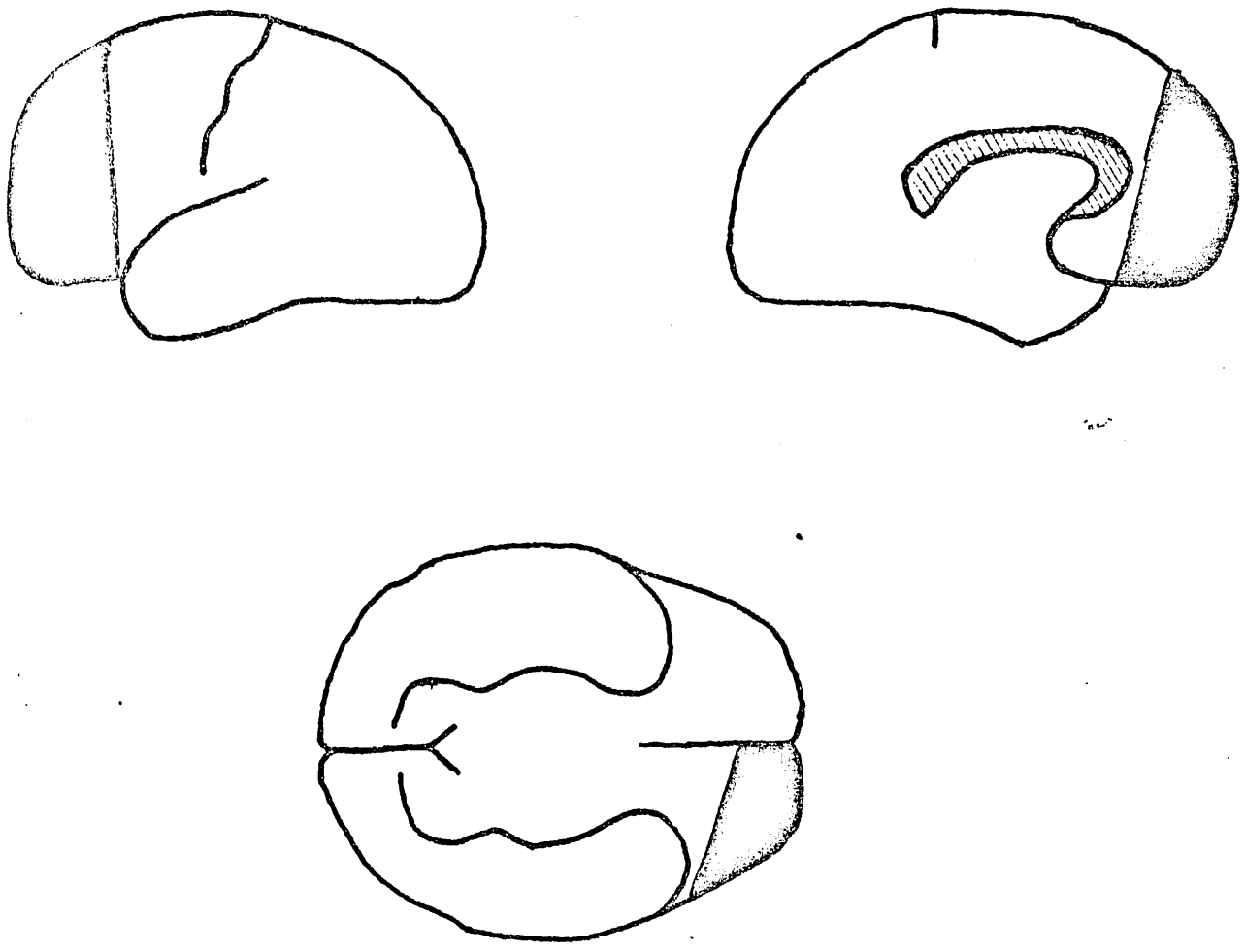


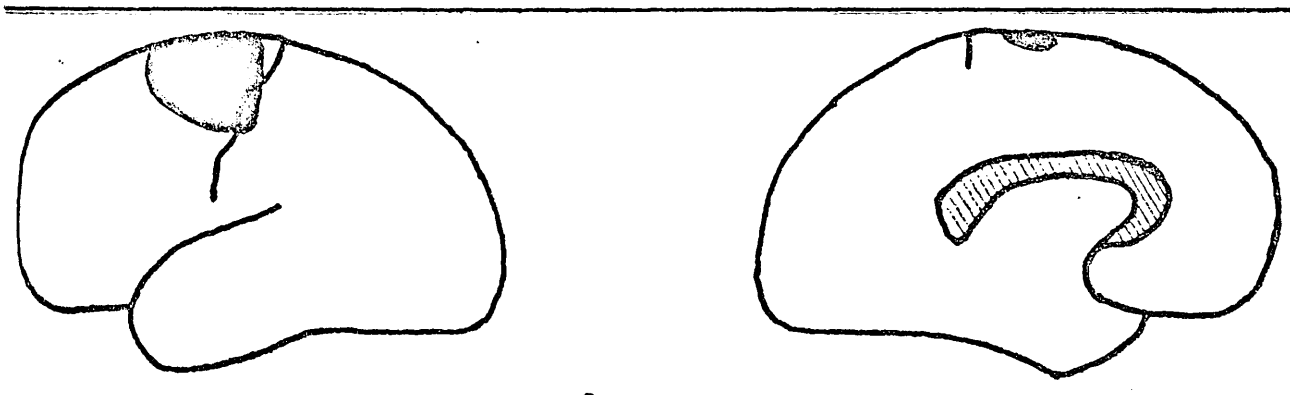




F6 W.B.



F7 D.N.



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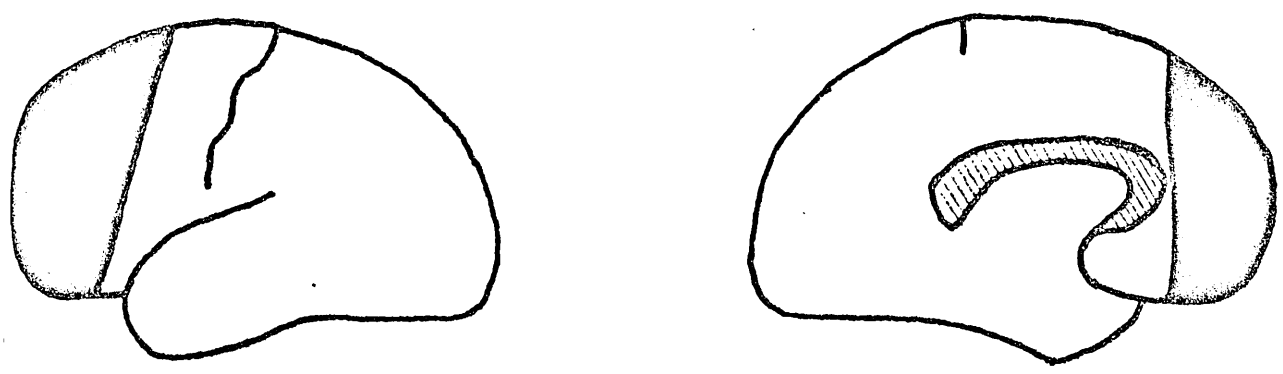

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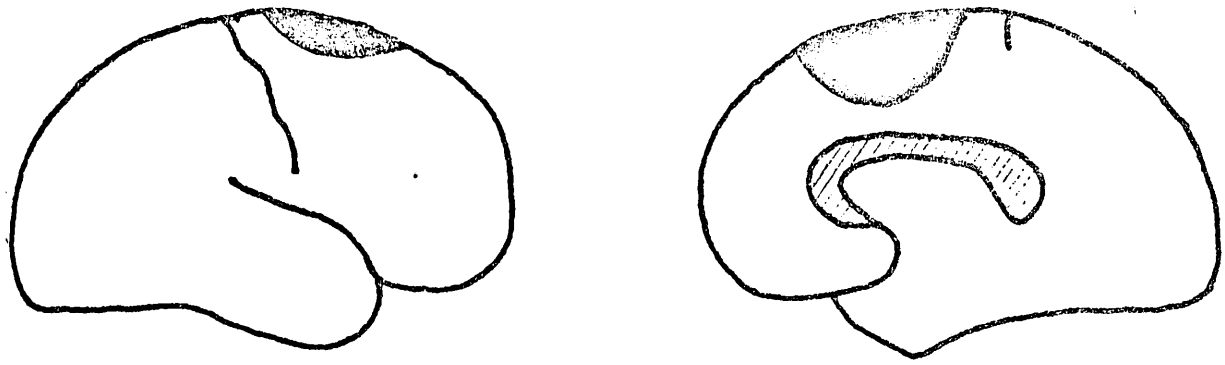
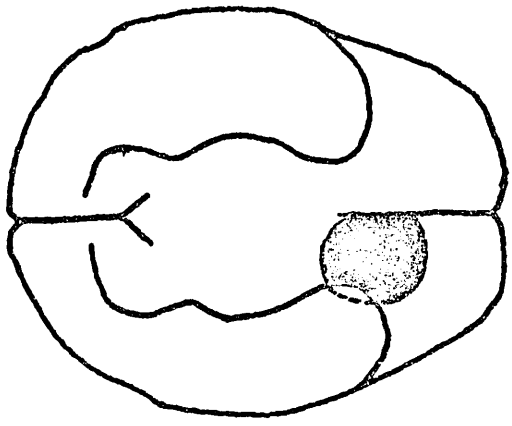
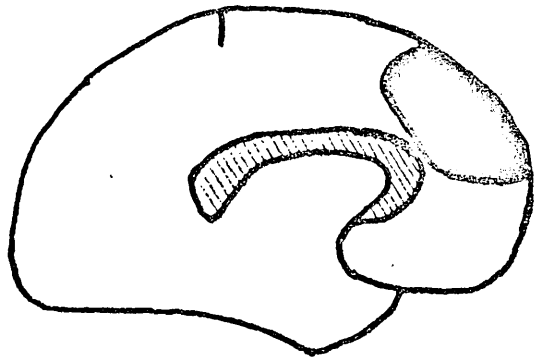


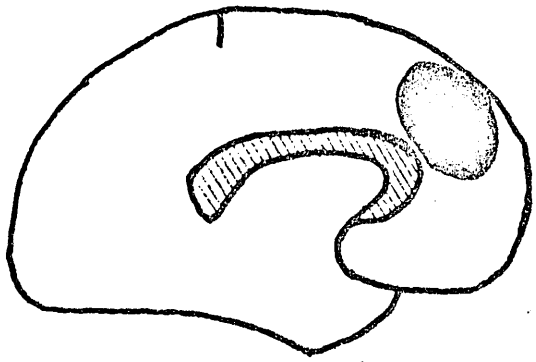
F10 F.D.



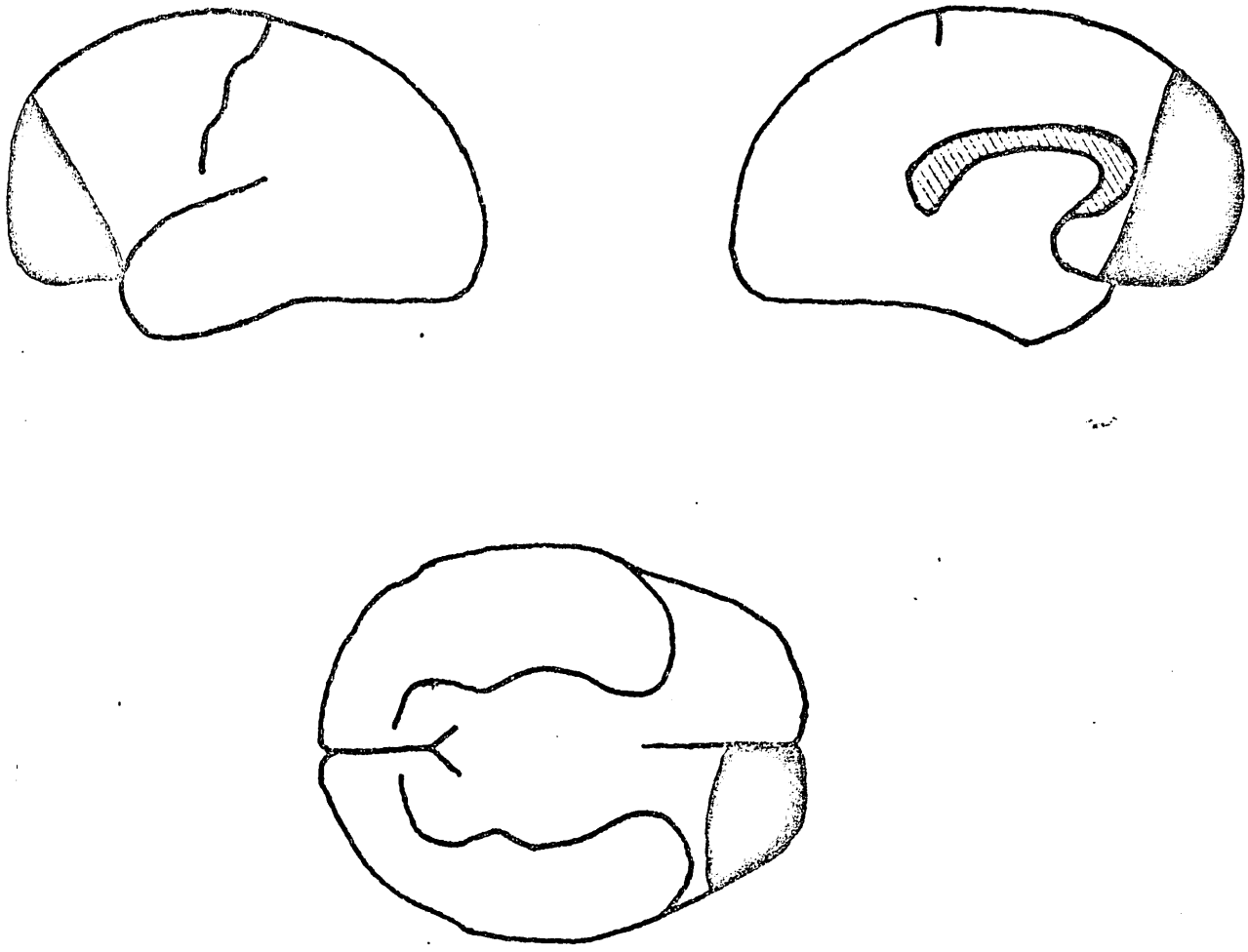
F11 A.M.



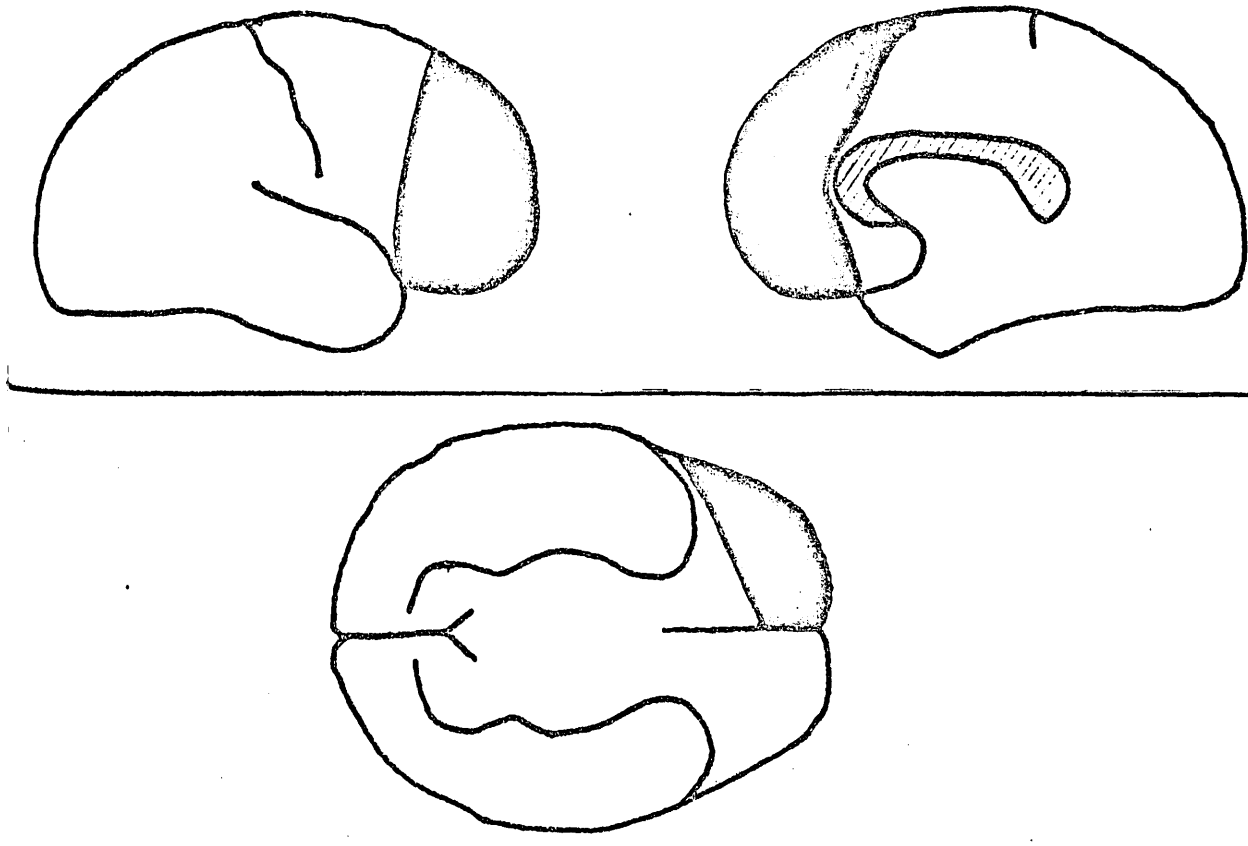
F12 I.N.



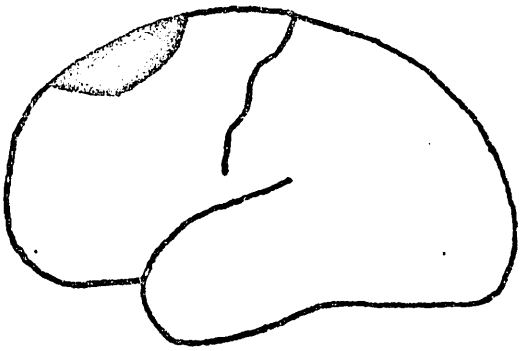
F13 E.S.



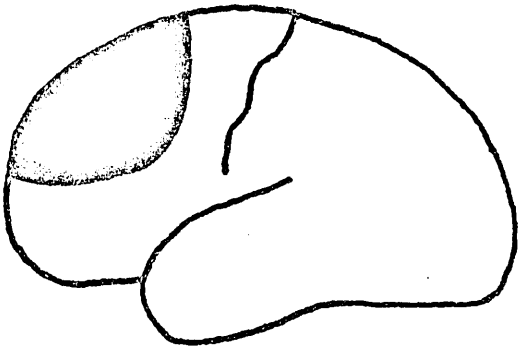
F14 E.S.



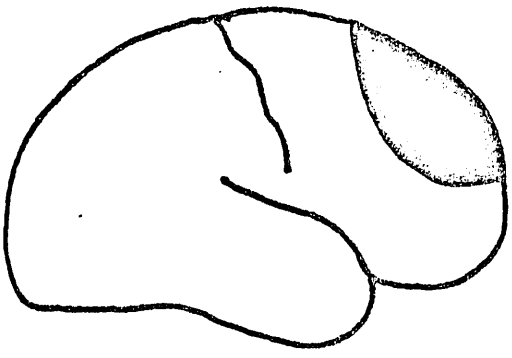
F15 A.M.

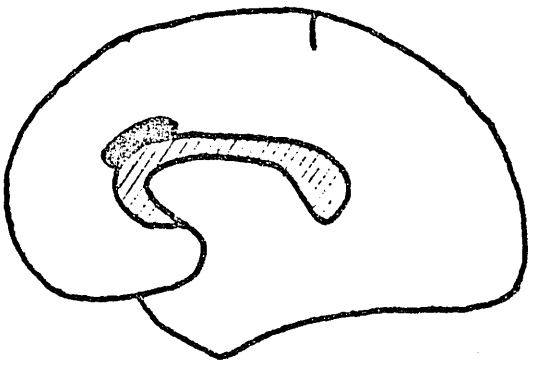


F16 B.V.

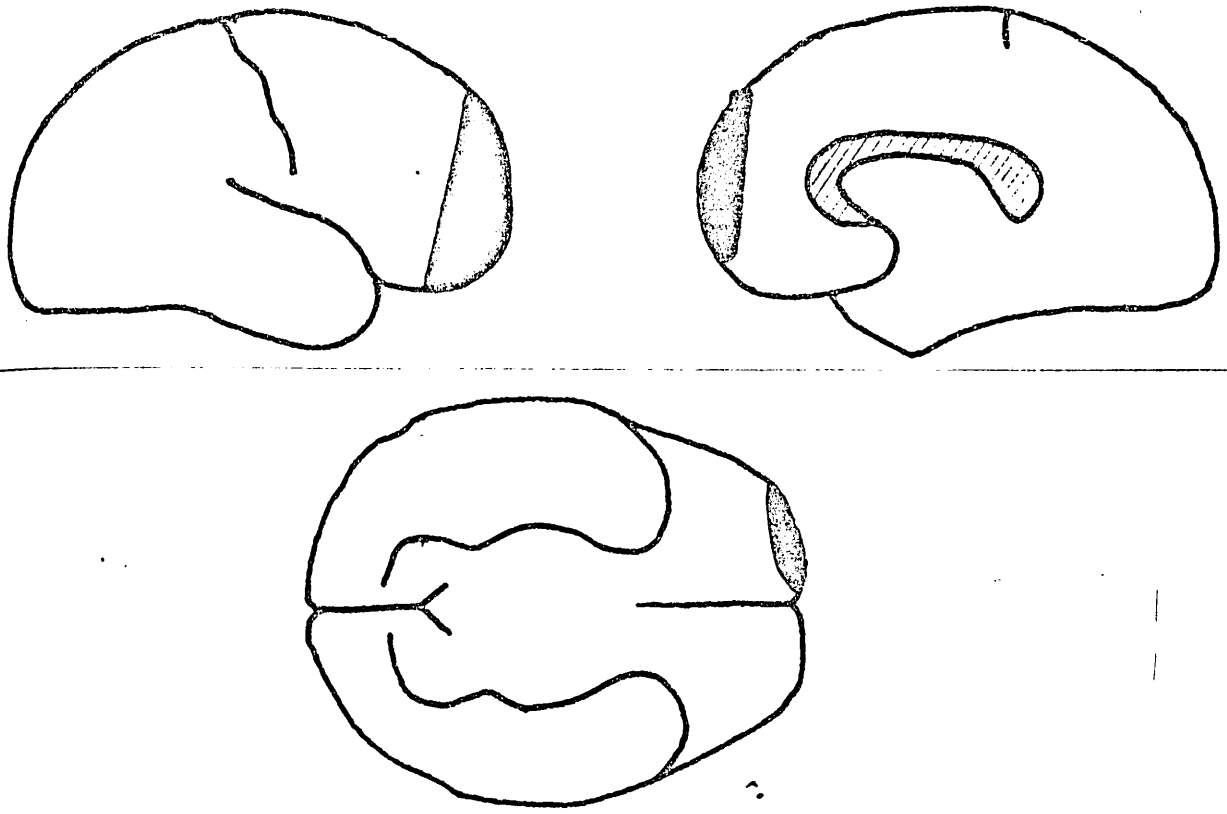


F17 C.S.

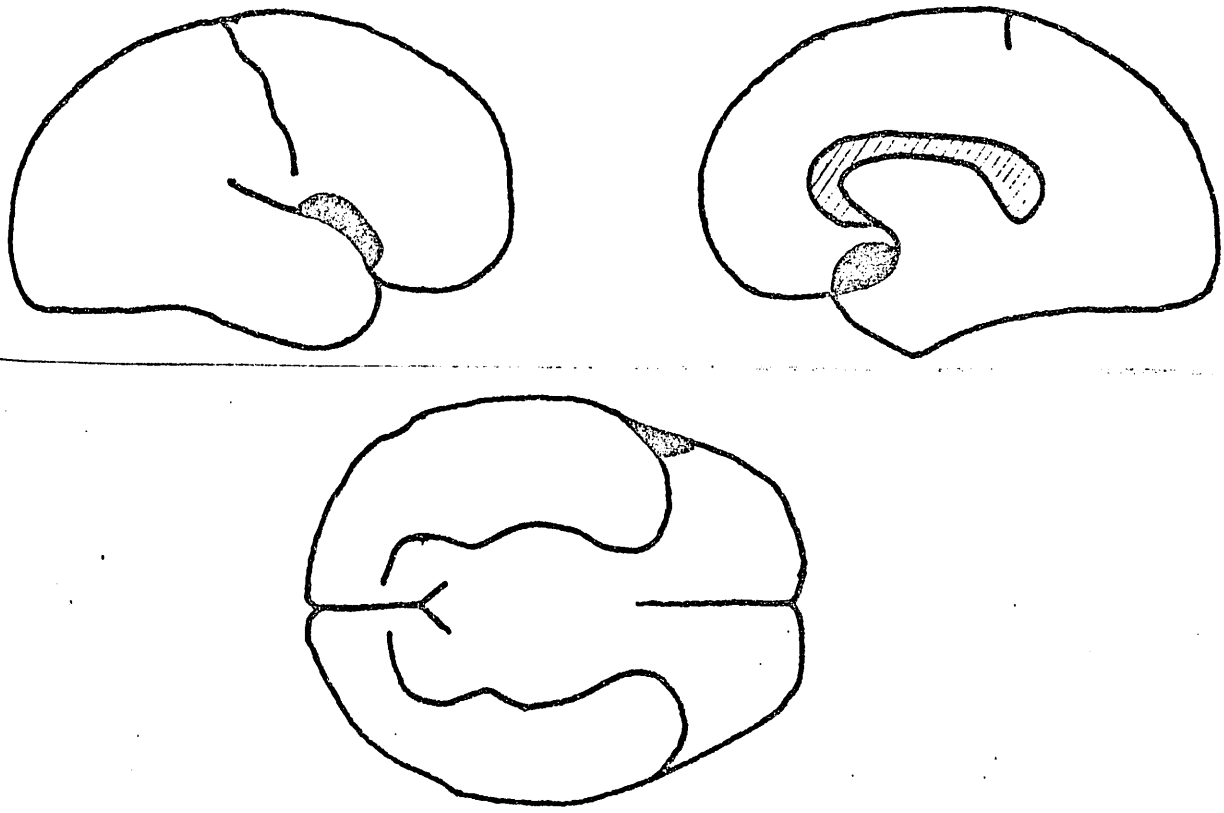




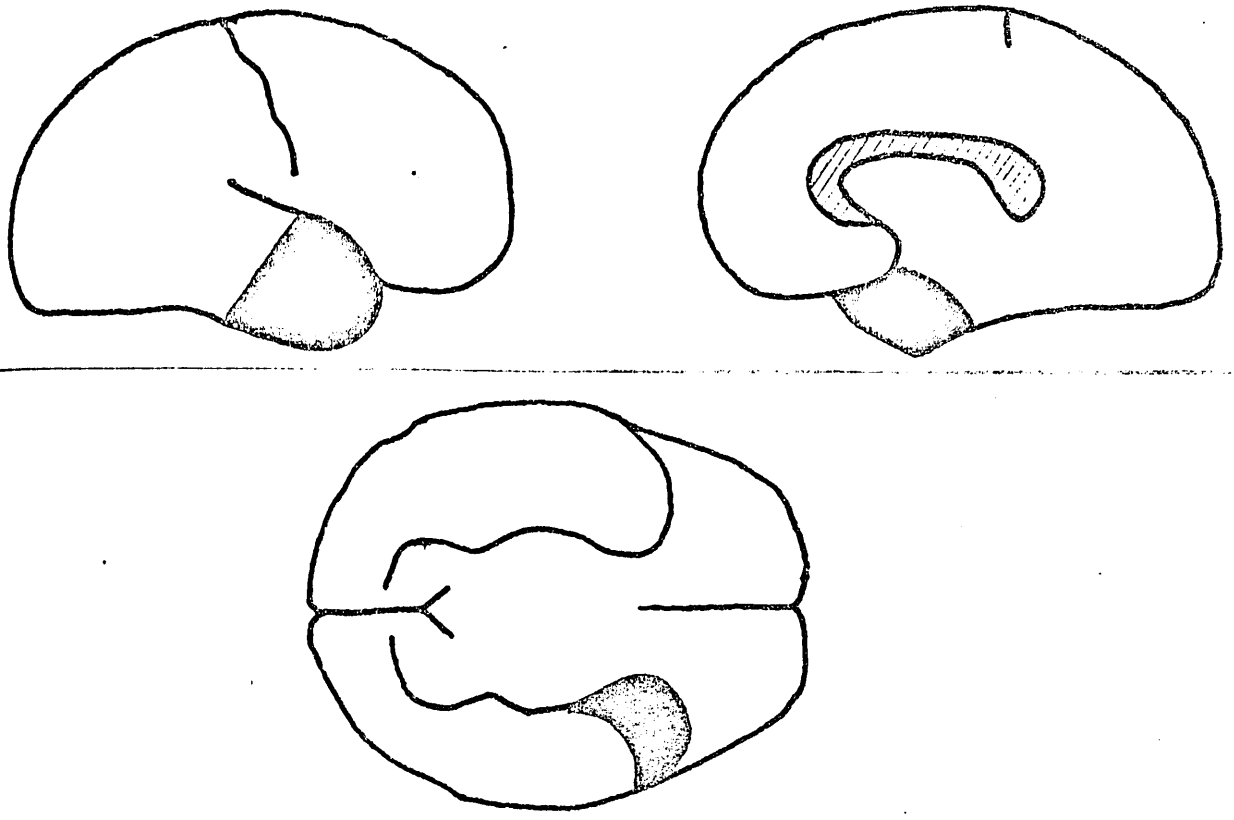
F18 D.M.



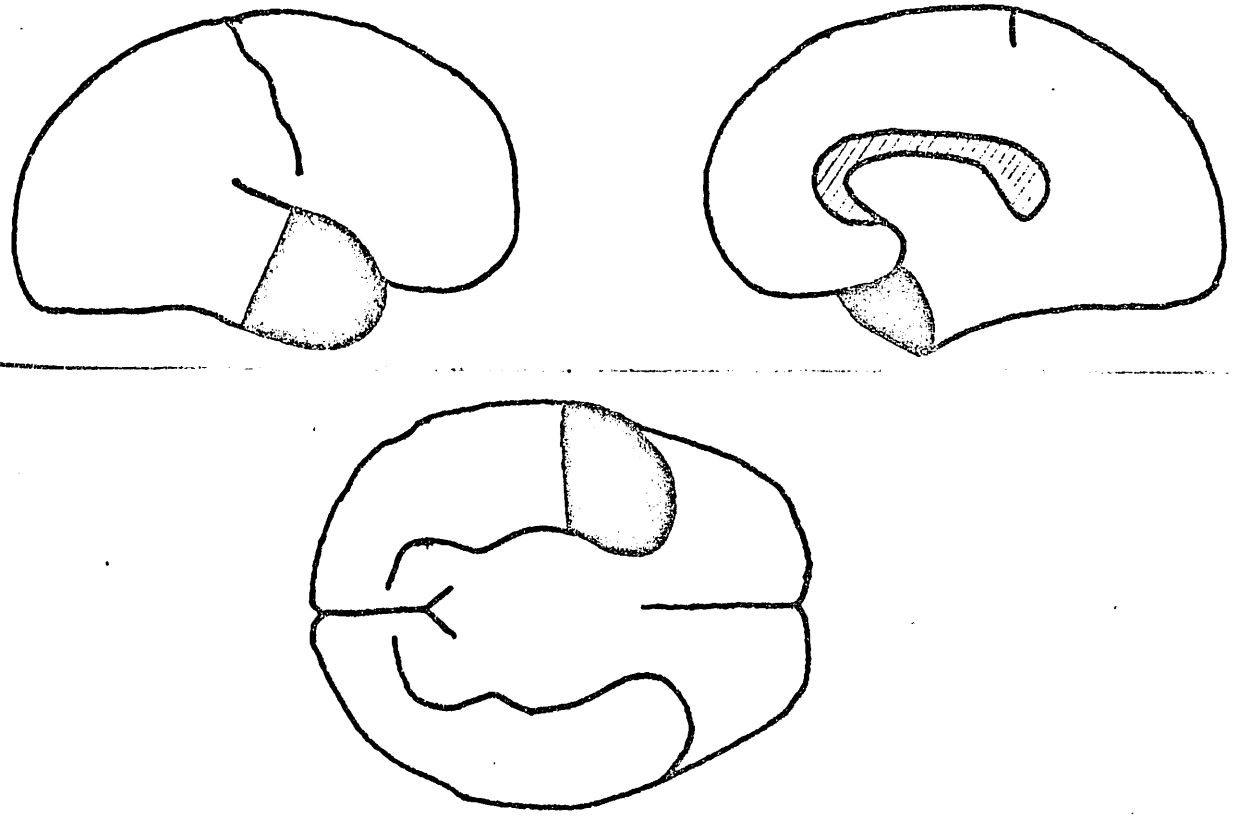
F19 G.P.



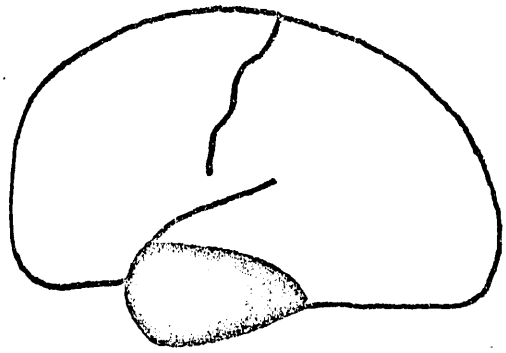
F20 M.C.

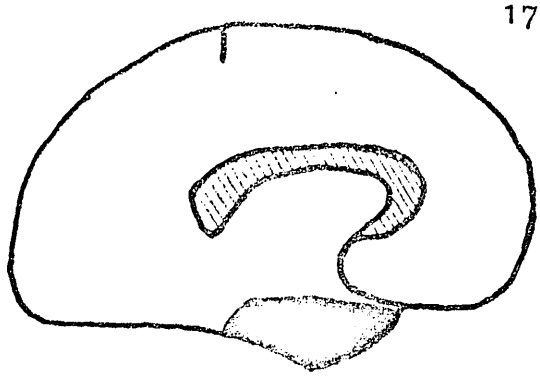


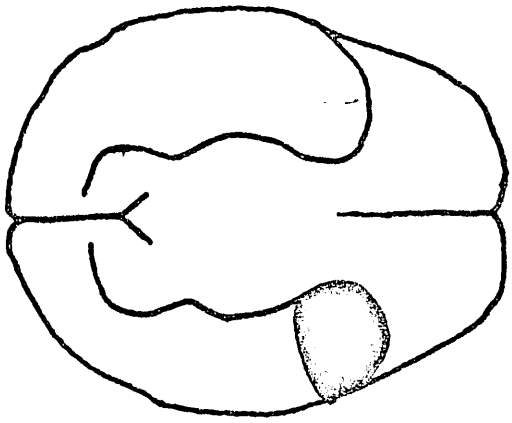
T1 S.J.



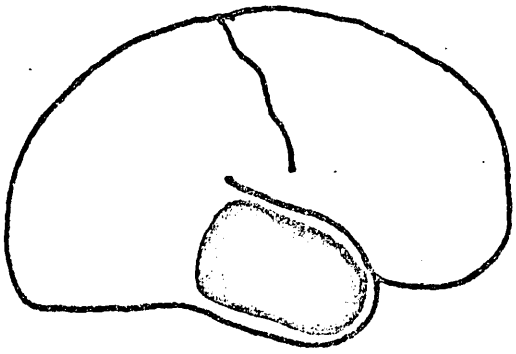
T2 W.S.

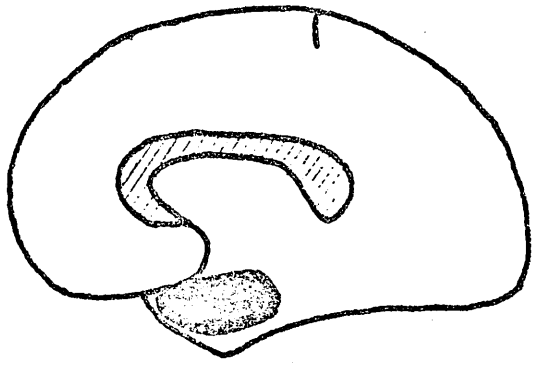


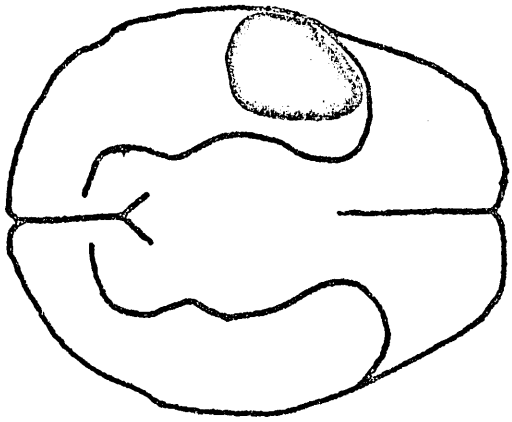




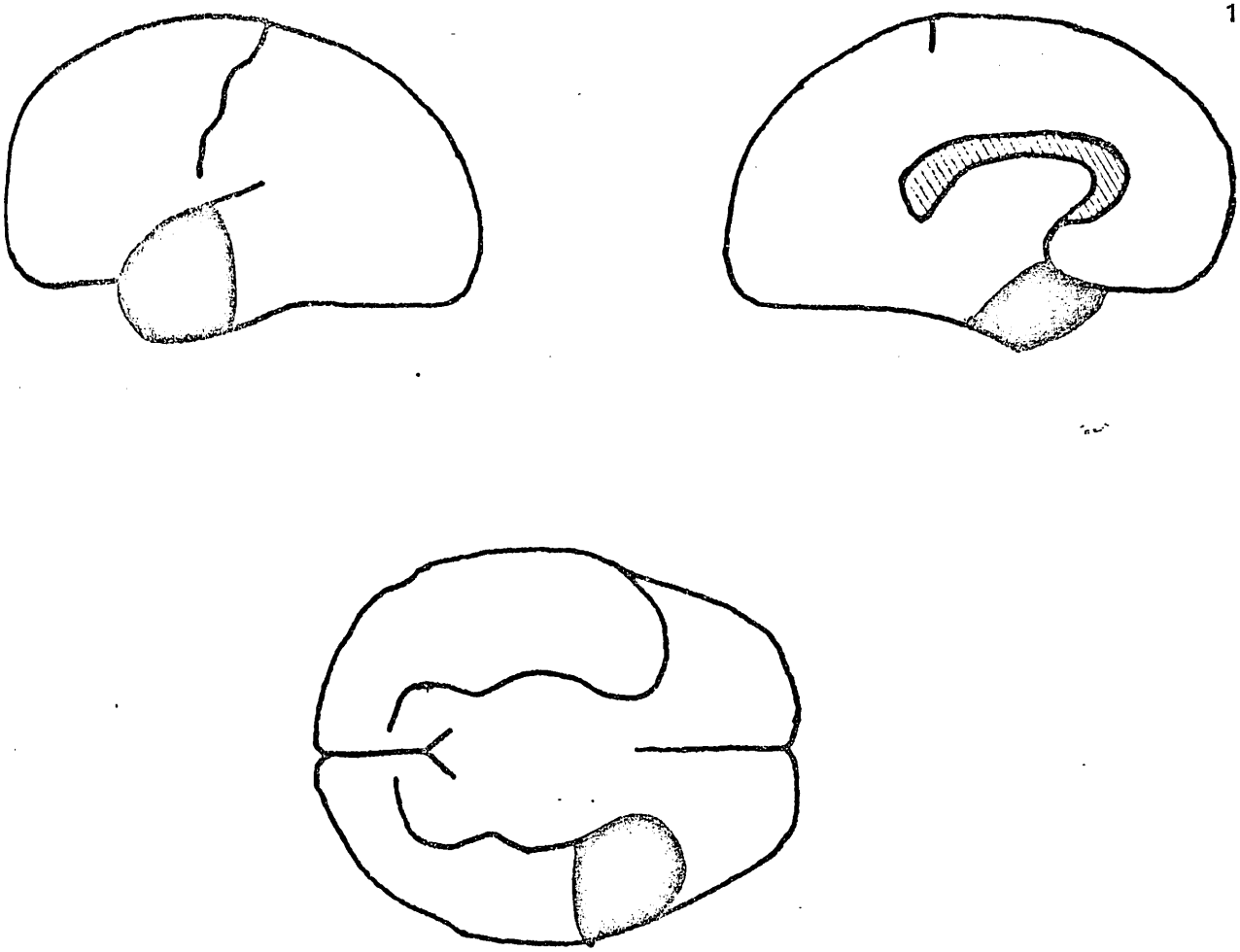
T3 J.B.



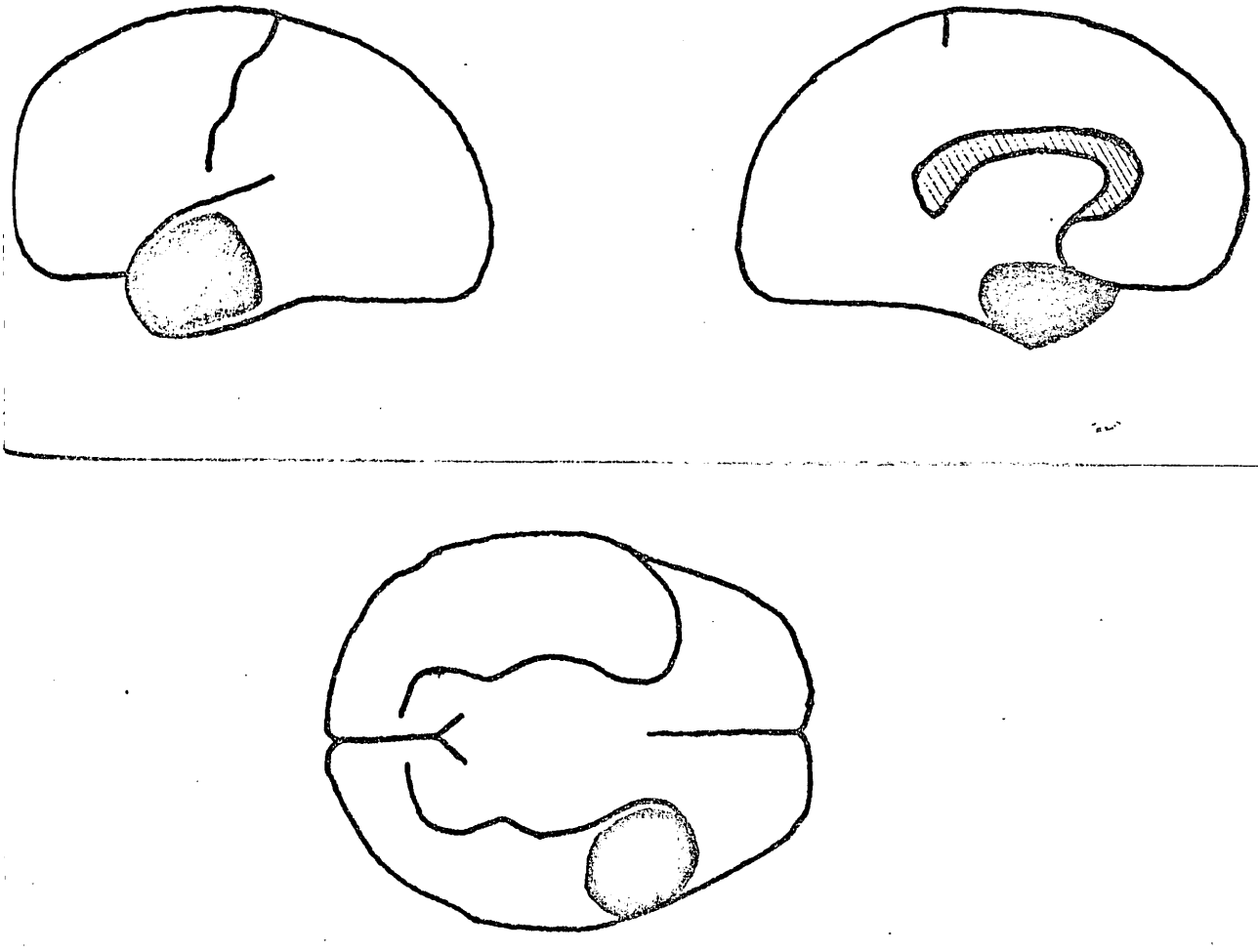




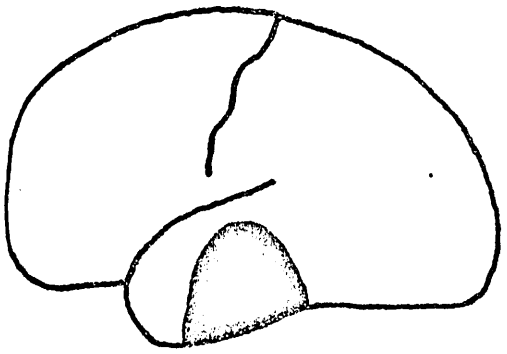
T4 O.D.



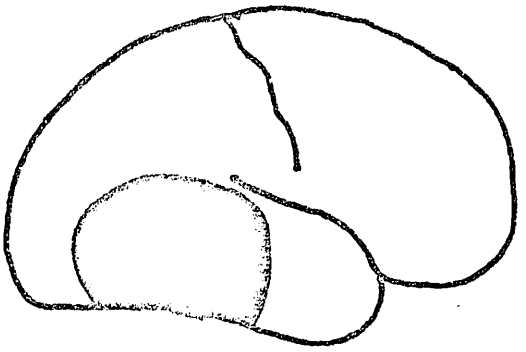
T5 J.B.



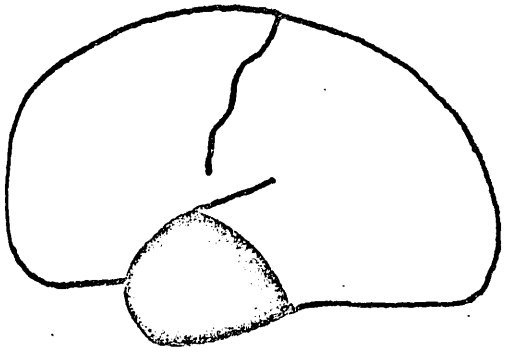
T6 M.R.



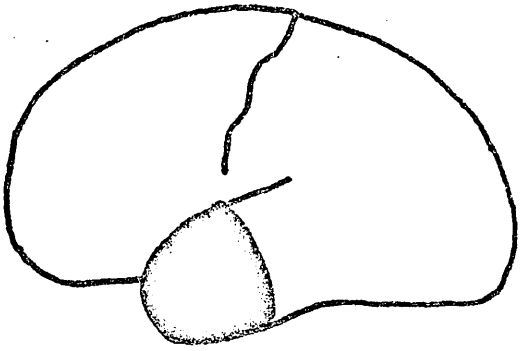
T7 M.I.



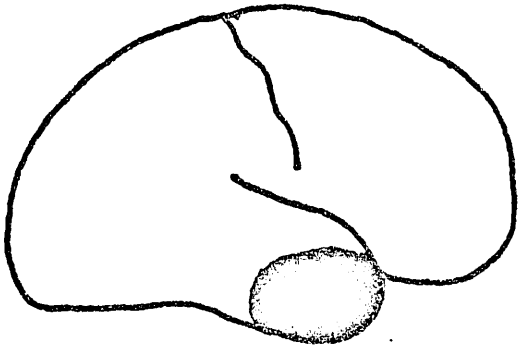
T8 M.W.



T9 G.S.



T10 R.A.



T11 P.C.

Appendix C

Analysis of Variance for Table 2 Total Trials to Criterion. (Experiment 1. Discrimination Learning)

Source	Sum of Squares	d.f.	Mean Square	F
Lesion (L)	672.30	2	336.15	3.17 $p > 0.05$ (2,27)
Task (T)	4.80	1	4.80	< 1
T. x L.	95	2	47.50	1.84 $p > 0.05$ (2,27)
S's within Lesion group	2862.40	27	106	
T. x S's within Lesion group	697.70	27	25.80	
Total	4332.2	59		

Planned Comparisons

Source	Sum of Squares	d.f.	Mean Square	F
Control v. brain-damaged	672.13	1	672.13	6.341 $p < 0.01$ (1,27)
S's within Lesion group	2862.40	27	106	
Frontal v. Temporal	0.10	1	0.10	< 1
S's within Lesion group	2862.40	27	106	

Appendix D

Analysis of Variance for Table 3 Alternation Score (Experiment 1. Discrimination Learning)

Source	Sum of squares	d.f.	Mean Square	F
Lesion (L)	346.30	2	173.15	1.86 $p>0.005$ (2,27)
Task (T)	70.42	1	70.42	1.94 $p>0.005$ (1,27)
T. x L.	155.43	2	77.71	2.14 $p>0.05$ (2,27)
S's within Lesion group	2518.45	27	93.30	
T. x S's within Lesion group	978.65	27	36.25	
Total	4069.25	59		

Planned Comparisons

Source	Sum of squares	d.f.	Mean Square	F
Frontal v. Temporal	152.10	1	152.10	4.45 $p<0.025$ (1,18)
*T. x S's within Lesion group	630.40	18	35.00	

*Control data excluded

Appendix E

Analysis of Variance for Table 4 Post Search Error Scores (Experiment 1. Discrimination Learning)

Source	Sum of squares	d.f.	Mean Square	F
Lesion (L)	2886.32	2	1443.15	1.42 $p > 0.05$ (2,27)
Task (T)	117.60	1	117.60	<1
T. x L.	2298.70	2	1149.35	5.76 $p < 0.025$ (2,27)
S's within Lesion group	16289.14	27	1018.10	
T. x S's within Lesion group	5388.70	27	199.61	
Total	26980.46			

Planned Comparisons

Source	Sum of Squares	d.f.	Mean Square	F
Frontal v. Temp.	2190.40	1	2190.40	8.167 $p < 0.025$ (1,18)
S's within Lesion Group	4827.70	18	268.21	

Appendix F

Analysis of Variance for Table 6 Perseverative Scores (Experiment 1. Discrimination Learning)

Source	Sum of Squares	d.f.	Mean Square	F
Lesion (L)	27.22	1	27.22	<1
Task (T)	5912.05	18	328.45	
T. x L.	42.02	1	42.02	<1
S's within Lesion group	38.03	1	38.03	
T. x S's within Lesion group	1479.45	18	82.19	<1
Total	7498.77	39		

Appendix G

Analysis of Variance for Comparisons of Visual Search Scores (Table 7) in Experiment 2. (Visual Search)

(i) Size of Positive Set (Comparison A)

Source	Sum of Squares	d.f.	Mean Square	F
Lesion (L)	32241.85	2	16120.93	4.51 $p < 0.025$ (2,26)
Task (T)	215786.92	2	107893.46	33.86 $p < 0.001$ (2,52)
T. x L.	24320.50	4	6080.13	1.91 $p > 0.05$ (4,52)
S's within Lesion group	92852.81	26	3571.26	
T. x S's within Lesion group	165715.25	52	3186.83	
Total	530917.33	86		

Planned Comparisons

Source	Sum of Squares	d.f.	Mean Square	F
Control v. brain-damaged	27158.00	1	27158	8.52 $p < 0.001$ (1,52)
S's within Lesion group	92852.81	26	3571.26	
Frontal v. Temporal	4386.20	1	4386.20	1.38 $p > 0.05$ (1,52)
S's within Lesion group	92852.81	26	3571.26	

Appendix G

(ii) Size of Negative Set (Comparison B)

Source	Sum of Squares	d.f.	Mean Square	F
Lesion (L)	166103.31	2	83051.66	6.89 $p < 0.01$ (2,26)
Task (T)	11656.16	2	5828.08	1.05 $p > 0.05$ (2,52)
T. x L.	21049.92	4	5262.48	< 1
S's within Lesion group	313798.40	26	12069.17	
T. x S's within Lesion group	289852.92	52	5574.10	
Total	802460.71	86		

Planned Comparisons

Source	Sum of Squares	d.f.	Mean Square	F
Control v. brain-damaged	163694.27	1	163694.27	13.56 $p < 0.001$ (1,26)
S's within Lesion group	313798.40	26	12069.17	
Frontal v. Temporal	1394.17	1	1394.17	< 1
S's within Lesion group	313798.40	26	12069.17	

Appendix G

(iii) Positive Set Class Size (Comparison C)

Source	Sum of Squares	d.f.	Mean Square	F
Lesion (L)	9920.9	2	4960.45	4.07 $p < 0.05$ (2,26)
Task (T)	1129.93	1	1129.93	5.53 $p < 0.05$ (1,26)
T. x L.	200.47	2	100.24	< 1
S's within Lesion group	31681.41	26	1218.52	
T. x S's within Lesion group	5309.7	26	204.22	
Total	48242.41	57		

Planned Comparisons

Source	Sum of Squares	d.f.	Mean Square	F
Control v. brain-damaged	9612.70	1	9612.70	7.89 $p < 0.01$ (1,26)
S's within Lesion group	31681.41	26	1218.52	
Frontal v. Temporal	464.02	1	464.02	< 1
S's within Lesion group	31681.41	26	1218.52	

Appendix H

Analysis of Variance for Table 8 sorting times (Experiment 3. Classification)

*Source	Sum of Squares	d.f.	Mean Square	F
Lesion (L)	1983.90	2	991.95	2.89 $p < 0.05$ (2,23)
S's within Lesion group	7903.23	23	343.618	
Position (P)	844.04	1	844.04	72.57 $p < 0.001$ (1,23)
P. x L.	5.62	2	2.81	<1
P. x S's within Lesion group	267.47	23	11.63	
Number (N)	0.05	1	0.05	<1
N. x L.	29.25	2	14.63	1.24 $p > 0.05$ (2,23)
N. x S's within Lesion group	270.83	23	11.78	
Novelty (Nov)	418.40	1	418.40	45.73 $p < 0.001$ (1,23)
Nov. x L.	11.87	2	5.94	<1
Nov. x S's within Lesion group	210.36	23	9.15	
Total	158678.0			

*Only main effects and their interaction with lesion type are shown

Appendix I

Analysis of Variance for total trials to criterion scores (Experiment 1. Discrimination learning) when data are rearranged according to hemisphere affected by lesion.

Source	Sum of Squares	d.f.	Mean Square	F
Lesion (L)	132.70	1	132.70	1.03 (1,15)
Task (T)	36.02	1	36.02	2.35 (1,15)
T. x L.	55.68	1	55.68	3.63 (1,15)
S's within Lesion group	1936.06	15	129.07	
T. x S's within Lesion group	229.80	15	15.32	
Total	2390.26	33		

Appendix J

List of items used in serial learning experiment (Experiment 4)

Low distractibility condition

6 J 3 J 9 J 8 J 4 J 2 J
7 Q 1 Q 8 Q 5 Q 4 Q 3 Q
9 R 3 R 5 R 2 R 4 R 1 R
6 B 9 B 2 B 7 B 5 B 8 B
2 F 4 F 3 F 5 F 1 F 9 F

High distractibility condition

5 A 8 N 6 S 2 W 7 X 4 T
2 P 4 E 3 X 1 G 6 L 9 J
5 E 2 D 1 L 4 A 9 W 3 F
1 U 2 F 8 B 5 K 9 N 7 V
9 Q 4 Y 5 Z 2 H 3 G 1 S

Appendix K

Analysis of Variance for Table 11 Serial Learning Scores (Experiment 4)

Source	Sum of Squares	d.f.	Mean Square	F
Lesion (L)	4.90	1	4.90	<1
Distracti-bility (D)	3.40	1	3.40	<1
D. x L.	0.00	1	0.00	<1
S's within Lesion group	455.80	13	35.10	
D. x S's within Lesion group	66.60	13	5.10	
Total	530.7	29		

Appendix L

Analysis of Variance for Table 14 decision speeds (Experiment 5)

Source	Sum of Squares	d.f.	Mean Square	F
Lesion (L)	3466.85	1	3466.85	<1
S's within Lesion group	3084590.55	13	237276.20	
Familiarity (F)	138240	1	138240	2.48 $p > 0.05$ (1,13)
F. x L.	3663.10	1	3663.10	<1
F. x S's within Lesion group	725450.90	13	55803.92	
Response (R)	8260.20	1	8260.20	<1
R. x L.	125906.50	1	125906.50	3.16 $p > 0.05$ (1,13)
R. x S's within Lesion group	518780.30	13	39906.18	
F. x R.	15617.13	1	15617.13	<1
L. x F. x R.	71687.32	1	71687.32	2.62 $p > 0.05$ (1,13
F. x R. x S's within Lesion group	355721.55	13	27363.20	
Total	5051384.40	59		

Appendix M

Analysis of Variance for Table 15 decision speeds (Experiment 6)

Source	Sum of Squares	d.f.	Mean Square	F
Lesion (L)	41.34	1	41.34	<1
Irrelevant Stimuli (I)	630.97	2	315.49	<1
I. x L.	782.83	2	391.42	<1
S's within Lesion group	67750.97	13	5211.61	
I. x S's within Lesion group	31769.53	26	1221.91	
Total	100975.64	44		

Appendix M(i)

Decision Speeds (m/secs) Experiment 6

				Condition 2						
Subject Number	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
Actual Score	368	503	576	587	590	421	931	626	559	533
Expected Score	290	397	455	464	466	333	736	495	442	421
Difference	78	106	121	123	124	88	195	131	117	112
				Condition 3						
Actual Score	495	632	576	599	571	373	985	577	468	399
Expected Score	482	615	560	583	556	363	958	561	455	388
Difference	13	17	16	16	15	10	27	16	13	11

				Condition 2	
Subject Number	T1	T4	T8	T9	T11
Actual Score	599	842	541	386	483
Expected Score	437	615	395	282	353
Difference	162	227	146	104	130
				Condition 3	
Actual Score	468	684	623	617	430
Expected Score	417	609	554	549	383
Difference	51	75	69	68	47

Appendix N

Total number of post-search errors in Experiment 1 (Discrimination Learning)

FRONTALS			TEMPORALS			CONTROLS		
Subject Number	Task 1	Task 2	Subject Number	Task 1	Task 2	Subject Number	Task 1	Task 2
F1	5	0	T1	5	3	C1	2	6
2	5	5	2	0	1	2	2	0
3	0	0	3	1	0	3	0	0
4	6	0	4	21	19	4	0	0
5	0	0	5	0	15	5	0	4
6	6	14	6	5	23	6	0	0
7	10	1	7	13	17	7	0	0
8	23	9	8	0	0	8	0	0
9	17	0	9	1	0	9	0	5
10	0	0	10	1	0	10	4	0

Appendix O

Total number of incorrect alternatives selected in Task 1 of Experiment 1. (Discrimination Learning)

	Frontals		Temporals		Controls	
Subject	F1	4	T1	7	C1	1
	2	2	2	0	2	4
	3	3	3	5	3	0
	4	1	4	3	4	0
	5	0	5	4	5	2
	6	8	6	6	6	1
	7	11	7	6	7	0
	8	3	8	0	8	0
	9	3	9	0	9	0
	10	0	10	2	10	3

Appendix P

Total number of perseverative errors in Experiment 1. (Discrimination Learning)

Subject Number	Frontals Task 1	Frontals Task 2	Subject Number	Temporals Task 1	Temporals Task 2	Subject Number	Controls Task 1	Controls Task 2
F1	5	10	T1	6	1	C1	0	2
2	3	5	2	0	3	2	0	0
3	0	0	3	0	0	3	0	0
4	5	2	4	7	8	4	0	0
5	0	0	5	11	8	5	0	2
6	4	6	6	9	7	6	1	0
7	5	0	7	11	2	7	0	0
8	11	5	8	0	0	8	0	0
9	9	9	9	0	0	9	0	9
10	0	0	10	2	0	10	6	0

Appendix Q

Total number of post-search errors in Discrimination Learning Task 1. (Follow-up study)

Subject Number	Frontals	Subject Number	Temporals
F11	17	T1	5
12	3	4	21
13	13	8	0
14	8	9	1
15	0	11	1
16	1		
17	3		
18	0		
19	5		
20	9		

Appendix R

Decision speeds (milliseconds) obtained in Experiment 6. (Conflicting Stimuli)

FRONTALS

		F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
Condition 1	Card 1	260	230	560	700	500	290	610	760	410	350
	2	410	560	440	440	760	380	1.260	500	640	350
	3	790	350	380	530	760	670	1.290	760	440	640
	4	260	410	580	530	1.050	380	2.340*	580	640	350
	5	260	730	580	560	640	380	1.230	470*	260	500
	6	440	580	380	960	670	290	1.170	730	470	470
	7	440	700	850	560	880	320	1.020	610	760	380
	8	380*	290	470	500	580	320	1.020	580	580	290
	9	320	410	960	670	700	350	500	610	260	350
	10	350	610	560	640	500	760	1.020	580	730	790
	Means	392	487	576	609	704	414	1.013	634	519	447
Condition 2	Card 11	260	260	470	790	560	290	1.020	730	500*	440
	12	410	440	560	200	610	290	1.050	580	640	500
	13	320	640	580*	1.050	410	290	2.660*	500	530	700
	14	410	290	500	470	640	500	820	610	790	470
	15	470	500	410	530	760	440	1.080	500	320	910
	16	410	880	560	290	470	320	2.160*	500	820	290
	17	410	470	610	410	610	410	580	760	530	560
	18	350	440	410	200	580	380	1.110	610	410	670
	19	260	670	1.020	1.290	850	560	560	530	350	350
	20	380	440	640	640	470	730	1.230	940	640	440
	Means	368	503	576	587	590	421	931	626	559	553
Condition 3	Card 21	440	560	700	580	610	350	1.140	670	470	610
	22	700	580	670	500	580	380	940	560	350	380
	23	380	640	530	580	640	350	1.230	560	440	260
	24	440	670	580	670	560	290	960	440	670	410
	25	530	380*	560	820	640	350	1.020	700	350	290
	26	200	380	640	440	560	320	820	670	410	260
	27	500	560	560	790	500	290	850	560	200	500
	28	940	640	500	530	560	470	960	530	470	560
	29	380	960	640	440	560	260	760	580	910	410*
	30	440	700	380	640	500	670	1.170	500	410	320
	Means	495	632	576	599	571	373	985	577	468	399

Appendix R (continued)

TEMPORALS

		T1	T4	T8	T9	T11
Condition 1	Card 1	530	330	840	370	450
	2	550	1.140	1.040	460*	270
	3	1.060	510	570	760	350
	4	720	710	660	440	930
	5	570*	1.380	430	390	640
	6	910	620	790	610	290
	7	910	360	480	330	250
	8	400*	470	680	230	310
	9	380	490	290*	650	300
	10	320	340	800	510	330
	Means	673	635	699	477	412
Condition 2	Card 11	870	1.190	690	430	520
	12	520	830	430	260	710
	13	650	360	440	460	810
	14	680	930	460	220	470
	15	450	1.140	600	370	330
	16	450	390*	590	370	350
	17	730	560	380	620	450
	18	430	650	760	340	390
	19	700	940	590	400	440
	20	510	980	470	310*	360
	Means	599	842	541	386	483
Condition 3	Card 21	660	560	410	990	380
	22	390	350	630*	330	470
	23	370*	270	980	650	560
	24	440	640	590	650	340
	25	300	1.050	740	510	310
	26	410	580	880	820	340
	27	530	930	560	550	730
	28	310	490	500	490	290
	29	750	1.120	350	540	620
	30	420	850	600	640	260
	Means	468	684	623	617	430

*denotes an error

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