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FRONTAL LESIONS AND SUSTAINED ATTENTION

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Abstract—Neurological patients were presented with a succession of 2–11 stimuli which they were required to count, reporting the number in the series when it finished. The stimuli were binaural clicks, or pulses on the right or on the left index finger. Regardless of stimulus modality or lateralization, patients with lesions involving the right frontal lobe were impaired when the presentation rate was 1/ sec. There was no corresponding impairment when the presentation rate was increased to 7/ sec. It is argued that at slow rates when the task was monotonous patients with right-frontal lesions were less able than others to sustain attention voluntarily.

INTRODUCTION

THERE ARE many studies of attentional disorders following frontal lobe lesions in animals and a long history of reports that in man such lesions can result in distractability [10]. There are, however, virtually no formal studies of the maintainance of attention by patients with frontal lobe lesions. In experimental investigations of patients with localised lesions it has been found that frontal lesions impair performance of tasks that require sustained attention, such as Wisconsin card sorting, maze learning and planning [6, 7, 12] but many other tests that also require sustained attention are performed quite normally [8, 13, 14, 15].

Most neuropsychological tests are demanding, and subjects who might otherwise exhibit distractability may fail to do so when a task demands their attention. The requirement for the voluntary imposition of attention on an uninteresting task arises mainly in tests of vigilance. We know of only one study of vigilance in patients with frontal lesions: that by SALMASO and DENES [11].

The experiment by Salmaso and Denes involved the performance of a simple continuous task. Identical letters or line stimuli were presented at a rate of one every 2 sec with an occasional novel stimulus of similar type which the subject was required to detect. A group of 10 patients with anterior lesions had a higher false-positive rate and lower sensitivity than a group of the same size with posterior lesions. This is just what one would expect if patients with frontal lesions were less able to sustain attention voluntarily. However an alternative possibility is that the anterior impairment may have resulted from impulsiveness (e.g. [4] p. 363), as subjects needed to make a rapid perceptual judgment in a go-no-go paradigm.

The study by SALMASO and DENES [9] derives from a long tradition of work on vigilance. In general, the vigilance tasks that have been used are not very suitable as clinical tests. They are both lengthy and extremely inefficient. Only on the rare occasions when a signal is presented can any failure of attention be observed, and the chances of a lapse of attention coinciding with a presentation of a signal are low. For these reasons we developed a short test in which any momentary lapse of attention would be likely to be detected, no matter when it occurred,

but for which the cognitive demands of the test were extremely simple. The tasks were derived from the literature on numerosity judgments [16–18]. The patient was presented with a train of stimuli and required to count them. As soon as the series ended, the patient had to report how many stimuli had been presented. At slow rates the counting task is relatively monotonous and successful performance depends on voluntary maintenance of attention. If attention lapses then the patient may stop counting, fail to stop counting at the end of the series or, most likely, fail to synchronize the counting with the stimulus train and so become confused as to which stimulus went with which digit.

Clearly any task, even one of this simplicity, must involve cognitive processes over and above those involved in voluntarily sustaining attention. One simple way of controlling for potential impairment of these more specific processes is to use higher rates of presentation. At high rates (e.g. 7Hz) the task requires relatively little in the way of sustained voluntarily attention: the task is subjectively demanding and "automatically" attracts attention without the subject having voluntarily to sustain it. Performance tends to be limited not by attention as much as the efficiency of the more basic processing mechanisms involved, particularly those required by counting. DORNIC [2], for example, showed that at high presentation rates the performance of bilingual subjects was poorer if they used their second language. Moreover, when the stimuli are auditory, performance is better than when tactile or visual stimuli are used [3, 18], suggesting a perceptual limitation, at least in the tactile and visual modalities. Any impairment of sensory, perceptual, or speech functions might therefore be revealed by numerosity judgments.

For the above reason numerosity tests involving different rates of presentation were chosen for use with neurological patients. Numerosity judgments were made for trains of stimuli with 2–11 stimuli per train, presented at rates ranging from very slow (1 Hz) to very rapid (7 Hz). The judgments were made for two stimulus modalities, auditory and tactile. The auditory modality was used on the assumption that it would be the least affected by sensory limitations, especially in patients with unilateral lesions. Tactile stimuli were also used, on the grounds that any general non-sensory deficits would be revealed in all modalities. Tactile stimuli were presented unilaterally to the index fingers of the right hand and then the left, so as to reveal any unilateral sensory deficits.

Two studies were conducted. The first was undertaken by the first author at the Montreal Neurological Institute between 1972 and 1974. The second study was designed as an attempt to replicate the results of the first with a different group of patients. It was conducted at the National Hospital in London between 1981 and 1982.

EXPERIMENT I

Subjects

The subjects were all patients undergoing unilateral neocortical removals for relief of intractable epilepsy. The details of the patients with frontal lobe removals are shown in Table 1. Patients were divided into four groups on the basis of the neocortical removal.

Although the removals were for relief of epilepsy, the patients in the anterior groups included one case of each of the following: cystic glioma, indolent astrocytoma, meningioma, angioma, and chronic encephalitis. Two patients with right temporal removal had a tumour. Ten of the 69 patients were not right-handed, but showed left-hemispheric speech representation after carotid injection of sodium amytal (R).

Apparatus

The signal "ready?" was recorded in a female voice on the first channel of a two-channel tape recorder and followed by a train of pulses on the second channel. The train of pulses was fed either to a loud speaker (for auditory presentation) or to a power amplifier (tactile presentation). The output of the power amplifier energised the lever of a

Table 1. Details of the sex, age, time since operation, full-scale (FS), verbal (V) and performance (P) IQs for patients participating in the first study. The standard deviations are shown in parentheses after the means

Patient group	*N* M/F	Age	Years since op.	IQs FS	V	P
Left frontal/ fronto-temporal	5/2	32(10)	3.7(3.6)	102(14)	100(11)	104(15)
Right frontal/ fronto-temporal	10/3	32(11)	7.7(8.8)	102(12)	105(12)	99(12)
Left temporal	11/12	28(8)	4.2(6.0)	104(15)	100(16)	108(13)
Right temporal	16/10	27(7)	2.5(3.6)	110(11)	109(11)	108(10)

small solenoid to which was attached a brass disc 5 mm in diameter that rested about 1 cm from the end of the subject's upturned index finger. The device applied a pressure of about 500 g/sq. cm which was increased momentarily when the solenoid was energised. Both auditory stimulation and tactile stimulation were easily detectable though not at all intense.

Procedure

Most patients received three tests, although the tests were not always completed in one testing session and a few patients failed to complete the later tests. The order of tests was (1) auditory clicks, (2) tactile pulses on the right index finger, (3) tactile pulses on the left index finger. Following familiarisation with the nature of the task and the stimuli, trains of stimuli were given at the following frequencies: 1 Hz, 2 Hz, 3 Hz, 5 Hz and 7 Hz in order of increasing frequency, and this order was repeated for each test. At each frequency 12 stimulus trains were presented in one of three constant random orders in which all trains with 2–11 stimuli were included at least once in the last 10 stimuli. If the subject made an error on any of these, a further ten (with 2–11 stimuli) were presented before the rate was increased. In practice this meant that nearly all patients received 22 trials at rates of 5 Hz and above. If subjects were uncertain as to the number of stimuli presented they were instructed to give their best guess.

RESULTS

In the Introduction it was emphasized how the qualitative nature of the demands made by the task change as a function of stimulus rate. For this reason errors made at the various stimulus rates were analysed separately.

At the 1 Hz rate patients with removals involving the frontal lobe of the right hemisphere made a greater number of errors than patients with exclusively temporal lesions, as may be seen from Table 2. On the auditory version of the test 2 of the 7 patients with excisions

Table 2. Performance on the numerosity tests. The scores for the auditory (A), tactile right hand (TR) and tactile left hand (TL) versions of the test are shown separately. Standard deviations appear in parentheses after the means

Patient group	Proportion of patients with errors at 1 Hz A	TR	TL	Mean % deviation at 7 Hz A	TR	TL
Left frontal/ fronto-temporal	2/7	2/7	0/6	10(3)	13(6)	16(5)
Right frontal/ fronto-temporal	7/13	7/11	7/10	23(11)	21(11)	24(12)
Left temporal	3/23	4/23	6/22	13(10)	19(10)	19(11)
Right temporal	2/28	6/26	4/26	18(10)	24(9)	22(12)

involving the left frontal region (29%) and 7 of the 13 patients with corresponding removals of the right hemisphere (54%) made at least one error. This may be compared with three out of 23 patients in the left-temporal group (13%) and 2 of the 28 in the right temporal group (8%). The difference between groups was significant ($\chi^2 = 13.36$ $P < 0.01$). Scheffé *post hoc* comparisons [5] revealed that the right anterior group made significantly more errors than temporal groups ($P < 0.01$). Performance of the left anterior group did not differ from that of the temporal groups.

On the tactile right hand version of the test the overall difference between groups was significant ($x^2 = 8.46$, $P < 0.05$) but Scheffé comparisons failed to reveal any significant differences between pairs of groups. On the tactile left hand version the difference between groups was once again significant and Scheffé comparisons revealed that the performance of the right anterior group was inferior to that of the left anterior and right temporal groups. In general, therefore, the performance of the right anterior group was impaired.

The errors were evenly divided between those of over- and those of underestimation on all versions of the test. All 7 of the patients with right anterior removals and one of those with left gave at least one estimate that differed from the correct value by two or more. This was the case in none of the patients with right temporal removals, and in only 2 of those with left. Scheffé comparisons showed significantly greater magnitudes of errors in the right anterior group as compared with the three other groups ($P < 0.03$). The magnitudes of the errors were not related to the number of stimuli in the train.

The right-temporal removals were generally less extensive than those involving the right frontal region but the effect of lesion size for patients with right anterior lesions was negligible: the Spearman rank correlation between removal size and mean performance at the slow presentation rates was -0.09. When the 5 patients with fronto-temporal removals were excluded the difference between patients with temporal removals and those with right-anterior removals was significant using planned comparison [4] on the auditory version ($z = 2.61$, $P < 0.01$) the tactile right ($z = 2.31$, $P < 0.01$) and tactile left ($z = 1.70$, $P < 0.05$).

At 7 Hz nearly all subjects underestimated the number of stimuli presented. The extent of underestimation increased approximately linearly with the number of stimuli presented. The error rate was not therefore the most sensitive measure of performance. To obtain a more sensitive measure, the difference between the number of stimuli presented and the number perceived was divided by the number presented. Twenty percentages (one for each of 20 stimulus trains given at high rates) were then averaged without respect for sign. The first two of the 22 trains, during which subjects were familiarised with the rapid presentation rate, were omitted. Therefore each stimulus value between 2 and 11 was represented twice. Table 2 shows the mean percentage scores for the patient groups. Separate non-parametric one-way analyses of variance [5] for the auditory, tactile right and tactile left conditions revealed significant differences between groups for the first two conditions but not the third ($\chi^2 = 11.05$, $P < 0.01$; $\chi^2 = 7.79$, $P < 0.05$; $\chi^2 = 2.92$, n.s., respectively). Subsequent *post-hoc* Scheffé analyses [5] failed to reveal any significant pairwise comparisons, but planned comparisons of left and right hemisphere groups revealed significantly greater underestimation in the right hemisphere groups on all three versions of the test ($z = 2.85$, $P < 0.01$; $z = 2.26$, $P < 0.01$; $z = 1.68$, $P < 0.05$ for auditory, tactile right hand and tactile left hand respectively). There were no significant anterior/posterior group differences.

A pattern of asymmetries which was broadly similar was observed at 5 Hz: the differences between groups were not significant, although planned comparisons of the left and right hemisphere groups [5] all reached significance (auditory: $z = 1.64$, $P < 0.05$; right hand:

$z=2.30$, $P<0.01$; left hand: $z=2.56$, <0.01). At 3 Hz and 2 Hz there were no significant differences between groups.

EXPERIMENT II

Patient sample

The patients in the second study were admitted to the National Hospital between May 1980 and December 1981. All were right-handed. The sample consisted of all patients who were assessed at the time as having a unilateral cortical lesion involving less than three lobes, who were fit enough to leave their ward and clinically free to do so. Localisation of lesions was based on CT scan except for two patients whose operation notes were used.

Patients were divided into frontal and non-frontal groups on the basis of the localisation of their lesion with respect to the plane bisecting, and perpendicular to, a line joining the nasion to the inion. Patients were placed in the "anterior" group if the bulk of their lesion was anterior to this line *and* the lesion involved the frontal lobes. Otherwise they were placed in the posterior group. As a result, any patient with a lesion confined to the temporal lobe was placed in the posterior group. No lesions were exclusively subcortical.

The patients all had tumours except for three in the anterior group (2 with infarcts, 1 with lobectomy for epilepsy) and four in the posterior group (1 with AV malformation, 1 with cyst, 1 with haematoma, and 1 with infarct). The mean age for the group was 48 and 49 respectively with male/female ratios of 5/8 and 7/8.

Methods

A shortened form of the auditory version of the previous test was used. As before, trains of clicks preceded by a "ready?" signal were given at a steady rate. The rate was initially 1 Hz and twelve trains ranging from 2 to 11 stimuli per train were given at this rate in a random order that was the same for all subjects. The rate was increased to 3 and then 5 Hz, two stimulus trains being given at each of these rates. Finally 22 trains were given at a rate of 7 Hz. At this rate each of the train lengths from two to eleven was presented twice with an additional two trains (of 2 and 11 stimuli respectively) to serve as practice at the outset.

RESULTS

The patient groups in this series were comparatively small and heterogeneous compared with the patients in the Montreal series. When the data were analysed as in Experiment I there were no significant differences between groups as regards the percentage deviations made at the 7 Hz rate. At the 1 Hz rate, however, it was once again the anterior groups who performed poorly. Three of the 6 patients in the left anterior group (50%) and 4 of the 6 in the right (67%) made at least one error. This is in marked contrast to the posterior groups: 2 of the 7 in the left-posterior group (29%) and only 1 of the 9 in the right-posterior group (11%) made errors. As in the first study the difference between right anterior and the remaining groups is significant (by planned comparison: $z=1.75$, $P<0.05$, 1 tail, [5]).

DISCUSSION

In both studies patients with anterior lesions of the right hemisphere made relatively frequent errors in counting auditory and tactile stimuli at slow rates of presentation. The aetiology of the patients who took part in the two studies differed considerably. In the first study the patients had undergone cortical removals for relief of intractable epilepsy. The surgical excisions were therefore well localised. Transient deficits in attention could have resulted from subclinical epileptiform abnormalities [1] and these could conceivably have been more pronounced in one of the patient groups. In the second study the patients were of mixed aetiology and did not have longstanding epilepsy. The two studies nevertheless gave similar results. The consistency between the studies suggests that the attentional deficits were not the result of epileptic abnormalities and can be attributed specifically to an effect of frontal lesions. It is also difficult to attribute the consistent findings of the two experiments to

the effects of practice alone, since in Experiment I errors occurred at slow rates on all three versions of the test (auditory, tactile right hand, tactile left hand) with considerable practice from one version to the next, and in Experiment II the opportunities for practice were more restricted.

The tasks that have previously been associated with frontal impairments are complex in structure and can in principle be performed according to a variety of alternative strategies. For this reason it has been difficult to dissect the particular aspects of the tasks responsible for the frontal deficits. The counting task used in the present studies would seem to be comparatively easy to analyse into component processes. It is significant that the frontal or anterior deficit occurred mainly at slow rates of stimulus presentation. The lack of such a deficit at rapid rates suggests that the numerical aspects of the task, minimal though they may be, are not, in and of themselves, specifically impaired by anterior lesions. By way of contrast, at the slow rates the patients impose attention voluntarily on an uninteresting task and attentional demands of the vigilance type are paramount. Errors on the task could have been due to a failure to synchronise the counting with the stimulus train, a failure to stop counting at the end of the series or both of these. In future studies it will be possible to determine the relative contribution of these processes by investigating the effects of, for example, trains of irregular stimuli, and trains of two different intermixed stimuli, only one of which has to be counted.

In the first study the errors at the rapid presentation rate in the auditory modality were associated with lesions of the right hemisphere although not specifically the right frontal region. Since all the patients in the first study showed left hemisphere dominance for speech it is unlikely that verbal aspects of the task were responsible for the deficits. It would appear instead that at high stimulus rates some non-verbal temporal patterning may have been impaired.

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