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Target Detection Deficits in Frontal Lobectomy

FRANCOIS RICHER, ANNE DÉCARY, MARIE-FRANCE LAPIERRE, ISABELLE ROULEAU, GUY BOUVIER, AND JEAN-MARC SAINT-HILAIRE

Hôpital Notre-Dame, Montréal

We examined the hypothesis of dorsomedial frontal lobe involvement in target detection through the effects of distractor interference and multiple target interference on unilateral lobectomy patients. Seven patients who underwent a unilateral frontal lobectomy for epilepsy involving dorsomedial cortex and variable amounts of lateral cortex were compared to 10 patients with a unilateral temporal lobectomy and to 10 normal adults on a visual character cancellation task. The task involved detecting occurrences of target characters embedded in rows of characters under three conditions: detection of one target character in the absence of distractors, detection of one target character among distractors, and detection of three targets among distractors. Visual detection performance was compared to that in the Stroop reading interference task. Frontals were predictably slower than the other groups in the baseline conditions of the character cancellation task and the Stroop task. After partialing out baseline detection performance in the character cancellation task, frontals showed an almost normal detection in the presence of distractors but were distinctly slower and made more errors than the other groups in multiple target detection. Frontals were also slower on the Stroop even after partialing out baseline naming performance. Temporals were normal on all tasks. Results suggest that frontal damage can affect selectivity in target detection as well as the Stroop and that this deficit is independent of the general psychomotor slowing observed in these patients. © 1993 Academic Press, Inc.

Human frontal lobe damage has been associated with a variety of deficits in attention-dependent activities. Some of the reported deficits that are most relevant to attentional selectivity have been characterized as distractibility (Hécaen, 1964; Laplane, Degos, Baulac, & Gray, 1981; Stuss, Kaplan, Benson, et al., 1982), concentration difficulties (Rylander, 1939; Luria, 1966), sensory neglect (Damasio, Damasio, & Chui, 1980; De Renzi, 1982; Heilman & Valenstein, 1972; Rafal, 1987), or visual search deficits (Luria, 1966; Teuber, 1964; Tyler, 1969).

For a number of reasons, including the complexity of attentional func-

Supported by the Fonds de la Recherche en Santé du Québec. Address reprint requests to F. Richer, Laboratoire de Neuroscience de la Cognition, Dept. de Psychologie, UQAM, Box 8888, Montréal, QC, Canada H3C-3P8.

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tions, clear anatomofunctional associations between specific prefrontal regions and attention-related cognitive operations have been difficult to establish. One such association was proposed by recent cerebral blood flow studies implicating the human medial frontal cortex in the visual detection of target stimuli among distractors (Petersen, Fox, Posner, Mintun, & Raichle, 1988; Posner, Petersen, Fox, & Raichle, 1988). Activation of this region appears to increase with the number of targets in sequences of visually presented words in a semantic classification task and is not activated in simple word repetition or in low event-rate vigilance tasks (Pardo, Fox, & Raichle, 1991). Posner et al. (1988) hypothesized that the medial frontal lobe is involved in a general attentional system recruited in target detection for the efficient control of response systems.

If the medial frontal cortex is involved in some aspect of target detection, lesions which include this region should produce clear detection deficits. Some evidence suggests that frontal damage (not necessarily medial) can produce deficits in target detection. Frontal lesions can affect auditory detection of repetitions of a single tone (Wilkins, Shallice, & McCarthy, 1987). They can also affect performance in the detection of rare novel visual stimuli presented among repetitions of a single stimulus (Salmaso & Denes, 1982). A recent case study also shows that a bilateral cingulotomy can produce temporary deficits in visual word classification (Janer & Pardo, 1991). This suggests that frontal damage can impair performance in tasks that involve detection of stimuli in sequences.

However, observations of impaired performance in target detection tasks are not sufficient to address the question of the attentional nature of the deficit. In order to be of relevance to attentional selectivity mechanisms, these detection deficits should be specifically attributable to the processing segregation of targets and nontargets and not to other factors such as general perceptual or response difficulties.

In the present study, this question was addressed by examining the effects of distractors and multiple targets in visual target detection. These two factors are known to affect the attentional segregation of targets and nontargets. Varying the heterogeneity of nontargets and their similarity to targets changes the distractor properties of nontargets, affecting detection performance (Duncan & Humphreys, 1989). Also, varying the size of the target set affects the complexity of the associative processes involved in detection, producing significant performance decrements (Duncan, 1980). The effects of distractors and multiple targets on detection were examined in a character cancellation task with hierarchical conditions with either (A) one target and no distractors, (B) one target among distractors, and (C) three targets among distractors. A deficit in attentional selectivity in target detection should show up in Conditions B and/or C even when partialing out baseline performance, whereas general perceptual or response deficits should affect all detection conditions equally.

This study examined the effects of distractors and multiple targets in detection in patients who underwent unilateral lobectomy in frontal regions for the relief of epilepsy. These lobectomies always included most of the anterior cingulate gyrus and dorsomedial frontal cortex and variable amounts of dorsolateral frontal cortex. The detection performance of frontal lobectomy patients was compared to that of patients with unilateral anterior temporal lobectomy and normals. The same groups were also compared on the Stroop task (Stroop, 1935) which also involves selective responding but where the challenge on selectivity comes from an habitual response tendency instead of categorical decisions on similar stimuli. The Stroop task has also been associated with medial frontal activation in PET (Pardo et al., 1990) and there is some evidence that it is sensitive to frontal damage (Perret, 1974).

METHODS

Subjects

Seven patients with a unilateral frontal lobectomy (5 right, 2 left), 10 patients with a unilateral temporal lobectomy (7 right, 3 left), and 10 normal adults participated in this study. Groups were equated for average age (mean, 35 years; range, 19–48 years) and average education level (mean, 11 years; range, 6–15 years).

All patients had suffered from drug-resistant epilepsy and were operated after 18 years of age. Anterior temporal lobectomies involved resection of the anterior portion of the temporal lobe (about 5 cm from the anterior tip of the lobe) including partial hippocampal removal and the sparing of Heschl's gyri. Frontal lobectomies were variable but always included resection of medial structures (anterior cingulate gyrus, superior frontal gyrus including supplementary motor area) and a variable degree of dorsolateral removal anterior to the precentral sulcus. Figure 1 shows the extent of frontal removal in the frontal patients tested. Patients were tested at least 1 year after the operation (average 5 years). Six of the seven frontals showed a significant reduction (80% or more) in seizure frequency after surgery (2/7 seizure-free) and all were on anticonvulsant medication. All temporals showed a significant reduction in seizure frequency (6 seizure-free) and half (5/10) were on anticonvulsant medication. None of the patients had any sensory or motor impairment in a clinical examination nor did they exhibit any hemispatial neglect in a standard full-page letter cancellation task (Weintraub & Mesulam, 1985). All patients had a WAIS IQ score (Wechsler, 1955) above 80. The average IQ of the two patient groups (frontals, 90; temporals, 103) was not significantly different ($t(15) = 1.1$, ns).

Tasks and Procedure

Visual target detection was tested via a character cancellation task adapted from the d2 test (Brickenkamp, 1966). The task involved searching through rows of 40 characters and crossing out occurrences of target characters randomly interspersed among other characters. In each row, the frequency of target characters was between 45 and 55%. Subjects were instructed to search through each row as fast as they could and cancel all occurrences of target characters while trying not to make any errors. Execution of each row was started by a signal from the experimenter.

The task was divided in three conditions. In each condition, subjects completed two practice rows and five test rows. Condition A involved detecting occurrences of a single

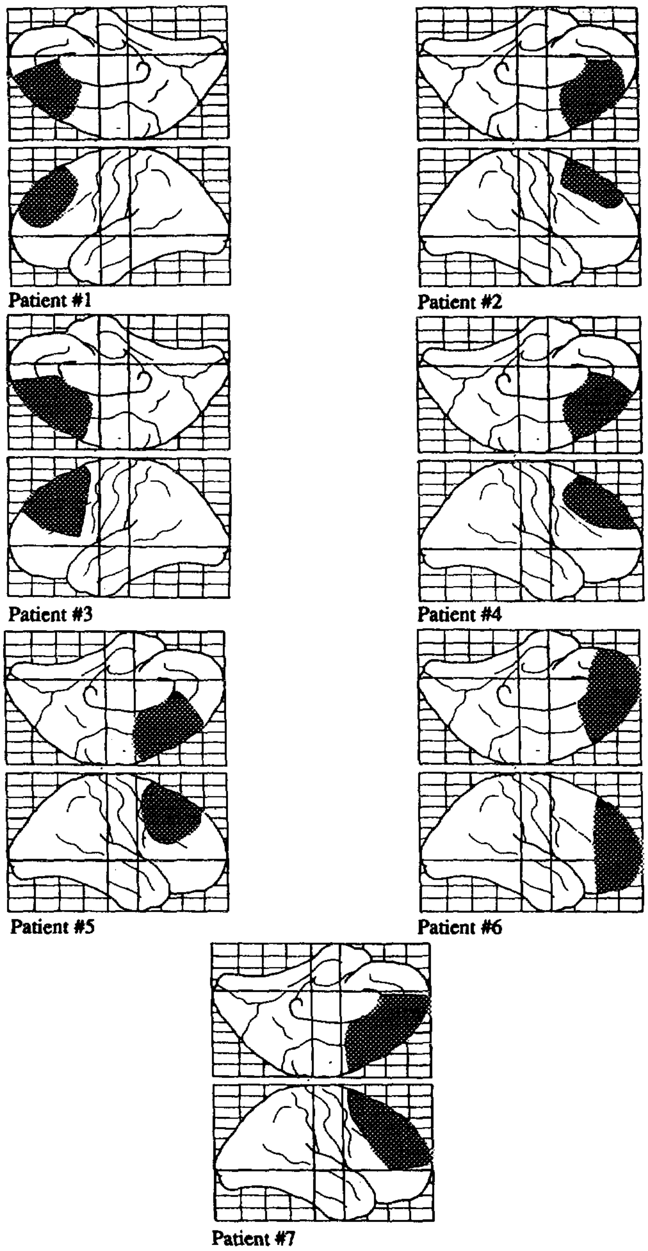

FIG. 1. Schematic representations of the extent of dorsomedial and lateral excisions in the seven patients with a unilateral frontal lobectomy.

TABLE 1
Average Performance Speed and Error Rates (%) of the Three Groups in the Target Detection Task and the Stroop Task.

	Frontals		Temporals		Normals	
	Speed	Errors	Speed	Errors	Speed	Errors
Visual detection						
Baseline (A)	3.04	—	4.2	—	5.07	—
	(.46)		(.83)		(.60)	
Single-target	1.56	0.8	2.23	0.8	2.26	0.8
detection (B)	(.15)	(0.5)	(.44)	(0.6)	(.39)	(0.6)
Three-target	1.02	4.7	1.63	2.0	1.62	1.0
detection (C)	(.13)	(2.5)	(.27)	(2.0)	(.12)	(1.2)
Stroop task						
Word reading (W)	1.46	—	2.02	—	2.51	—
	(.39)		(.37)		(.26)	
Color naming (C)	1.08	—	1.61	—	1.82	—
	(.24)		(.31)		(.15)	
Color naming with	0.49	1.4	0.85	0.8	1.10	0.6
Interference (CW)	(.14)	(1.6)	(.19)	(1.7)	(.09)	(1.1)

Note. Speeds are in items/sec. Standard deviations are in parentheses.

target character (d) randomly interspersed among ds. Condition B involved detecting occurrences of a single character (ḍ) among distractor characters (ḋ, d̤, and d̈). Under Condition C, subjects had to detect occurrences of three different target characters (ḍ̇, d̈, and d̤) among distractors (ḋ, ḍ, ḋ̤, ḍ̈, and d̤̈). In this condition, the target set was selected for the ease with which it could be remembered. Subjects were told that the targets were all the characters with two marks and the subjects' recall of the targets was tested after two test rows had been completed. Distractors were selected so that each target had at least two distractors differing from it by only one mark, as was the case under Condition 2, to minimize variations in target–nontarget similarity between the two conditions.

The three conditions were always given in order of increasing complexity so as to ensure that all subjects would be exposed to the different aspects of the task in the same sequence and one at a time. In each condition, the average time taken to complete a row and the average number of omissions and false detections were noted.

The Stroop color–word interference task (Stroop, 1935) was composed of three conditions: (1) reading of words representing color names (W), (2) color naming of colored patches (C), and (3) color naming of the ink in which words representing incompatible color names were typed (CW). In each condition, the number of items completed in 45 sec and the number of errors not immediately corrected were noted.

RESULTS

Table 1 summarizes the performance of the three groups on the two tasks, with all speed scores converted to items/second. In the character cancellation task, frontals showed a poor performance in all conditions. In the baseline condition, frontals were significantly slower than normals, whereas temporals had a normal performance ($F(2, 24) = 20.2, p < .001$, Tukey's *HSD* = 2.08, $p < .05$ between frontals and normals). None of the subjects made any error in the baseline condition.

The effect of distractors on performance speed was examined in an analysis of covariance (ANCOVA) on scores under condition B, using scores under condition A as covariate. In this analysis, frontals were only slightly slower than normals and temporals were not significantly slower than normals ($F(2, 23) = 2.98$, $p = .07$). Errors were extremely rare in the distractor condition in all three groups and error rates did not differ among the groups ($F(2, 24) = .94$, ns).

In multiple target detection (condition C), speed and accuracy were lower than in the other two conditions in all groups. All subjects correctly reproduced the three target characters from memory upon being asked after completing two test rows. The effect of multiple targets on performance speed was also analyzed through ANCOVAs on scores under condition C, using scores under condition B as covariate. Frontals were significantly slower than normals but this was not the case for temporals ($F(2, 23) = 13.2$, $p = .001$, $t(23) = 3.64$, $p = .001$ between frontals and normals).

In contrast to the other conditions, error rates were not negligible in multiple target detection, and omissions were more frequent than false detections in all groups. Error rates were also significantly higher in frontals than in normals, whereas temporals did not differ from normals ($F(2, 24) = 4.0$, $p < .05$, *HSD* = 2.3, $p < .05$ between frontals and normals). Both omissions and false detections rates were significantly higher in frontals compared to the other groups (all $Fs(2, 24) > 3.5$, $p < .05$).

In the Stroop task, frontals were significantly slower than normals in both word reading (W) and color naming (C), whereas temporals did not differ from normals (all $Fs(2, 24) > 5.0$, $p < .05$, all $HSD < 16.0$, $p < .05$). Error rates were negligible in these two conditions.

As with the visual detection task, the reading interference effect of the Stroop was analyzed using ANCOVAs on the scores of the CW condition using the scores of both C and W conditions as covariates. Again, frontals were slower than the other groups, whereas temporals did not differ significantly from normals ($F(2, 23) = 3.4$, $p = .05$, $t(23) = 2.6$, $p = .01$ between frontals and normals). Error rates were generally low and did not differ significantly among the groups ($F(2, 24) = 0.9$, ns).

DISCUSSION

Their performance in the cancellation task indicates that frontals have more difficulty with visual multiple target detection than normals and temporals. This effect cannot be attributed to general factors such as oculomotor difficulties or nonspecific slowing that would contribute to all conditions of the task, since it is present even when the baseline detection performance is partialed out, and it cannot be attributed to a failure to remember the associative rules of the task since all patients were able to recall them. These observations are compatible with the hypothesis that frontals show a selectivity deficit in target detection.

In multiple character cancellation, all frontal patients were slower and made more errors than the worst subject in the normal group, including patient 2 who suffered little damage laterally to the superior frontal sulcus. This could suggest that the critical lesion is in the dorsomedial portions of the frontal lobe. However, data on more restricted medial frontal lesions from cerebrovascular accidents and from patients with frontal lesions excluding the medial portions will be necessary to confirm this suggestion.

Frontals also showed a selective response difficulty in the Stroop task. This result is compatible with the PET data of Pardo et al. (1990) and also agrees to some extent with the effects of frontal neoplasms (Perret, 1974) although we could not find the left hemispheric preponderance suggested in that study.

The coexistence of deficits in multiple target detection and Stroop may indicate that these lesions affect the efficiency of S–R associations under circumstances in which response specification is not trivial and subject to control errors. In multiple target detection, these circumstances are provided by the many-to-one S–R association rule and in the Stroop by the habitual association between word stimuli and reading response. In this perspective, these deficits could be associated with processes that contribute to performance selectivity (attention) through the regulation of S–R associations as suggested in some perspectives in cognitive psychology (Allport, 1987).

The frontal lesions investigated here are similar to those that have been reported to produce deficits in associative learning (Petrides, 1985) and in novelty detection (Milner, 1964, 1982), which may bear some relationship to the problems observed in the present study. Future studies should systematically address the question of the involvement of various frontal regions on the various aspects of efficient S–R association or selective responding.

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