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VARIABILITY IN THE IMPAIRMENT OF RECOGNITION MEMORY IN PATIENTS WITH FRONTAL LOBE LESIONS

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ABSTRACT

Fourteen patients with frontal lobe lesions and 14 normal subjects were tested on a recognition memory task that required discriminating between target words, new words that are synonyms of the targets and unrelated distractors. A deficit was found in 12 of the patients. Moreover, three different patterns of recognition impairment were identified: (I) poor memory for targets, (II) normal hits but increased false recognitions for both types of distractors, **(III)** normal hit rates, but increased false recognitions for synonyms only. Differences in terms of location of the damage and behavioral characteristics between these subgroups were examined. An encoding deficit was proposed to explain the performance of patients in subgroup I. The behavioral patterns of the patients in subgroups II and **III** could be interpreted as deficient post-retrieval verification processes and an inability to recollect item-specific information, respectively.

Key words: frontal lobes, episodic memory, recognition processes, false recognition

INTRODUCTION

A number of neuropsychological studies have demonstrated that the frontal lobes play an important role in episodic memory. Evidence for this comes from studies showing that patients with lesions of the frontal lobes are impaired in free recall (Gershberg and Shimamura, 1995; Incisa della Rocchetta, 1986; Jetter et al., 1986; Stuss et al., 1994), as well as in memory for contextual information (Janowsky et al., 1989; Kesner et al., 1994; Kopelman et al., 1997; McAndrews and Milner, 1991; Milner et al., 1991). Initially, it was believed that recognition memory was relatively unaffected by frontal lobe damage (Jetter et al., 1986; Milner et al., 1991). In their meta-analysis, Wheeler et al. (1995) suggested that frontal lobe patients were more frequently impaired on free recall (80% of the cases) than on cued recall (50%), and that cued recall itself was more often impaired than recognition memory (8%). This was attributed to the greater demands that recall places on strategic retrieval processes, compared to recognition memory. Consistently, Gershberg and Shimamura (1995; see also Stuss et al., 1994) have demonstrated that the frontal lobe patients failed to initiate and use organizational strategies at encoding and at retrieval during free recall tasks.

However, recent case studies and group studies have shown that recognition memory can also be impaired following frontal lobe lesions. Moreover, it appears that there is some variability in the recognition performances of frontal lobe patients.

First, the presence of a recognition memory deficit following damage to the frontal lobes may depend on the kind of recognition test used. Parkin et al. (1994) reported that a patient (C.B.) who had suffered from a rupture of an anterior communicating artery (ACoA) aneurysm was impaired on recall tasks, performed well on forced-choice recognition memory tests, but showed lower scores on yes/no recognition tasks. This can be interpreted by reference to dual-process models of recognition memory (Mandler, 1980; Yonelinas, 1994), which suggest that at least two processes contribute to recognition memory: recollection and familiarity. Recollection has been described as a recall-like process, involving the conscious retrieval of an event together with its encoding context. By contrast, familiarity refers to knowing that an event has previously occurred, without any recollection. Parkin et al. (1994) suggested that C.B. was able to use familiarity to discriminate between targets and distractors presented simultaneously, but failed to recollect the items in the yes/no tasks. Consistently, a recent study by Bastin and Van der Linden (2003) has shown that familiarity makes a greater contribution to forced-choice than to yes/no recognition memory, whereas yes/no recognition memory tends to require more recollection.

Second, several case studies have documented a particular pattern consisting of relatively good recall performance (although marked by many intrusions) and impaired yes/no recognition memory performance, with a normal hit rate and a great amount of false recognitions (Delbecq-Derouesné et al., 1990; Parkin et al., 1996; Schacter et al., 1996; Ward and Parkin, 2000). In those studies, interpretation of this pattern of recognition performance was made in light of the theoretical framework provided by constructive views of episodic memory (see Schacter et al., 1998, for a synthesis). According to these views, appropriate encoding of an episode necessitates the encoding of the specific details of the event and its associated context into a coherent memory trace, which does not overlap with the traces of similar episodes. At retrieval, the representation of the episode may be automatically reactivated if the information contained in the retrieval cue match sufficiently the memory trace. Otherwise, one can engage into strategic retrieval processes. These processes imply the building of a description of the sought-after episode which holds as much characteristics specific to the episode as possible, in order to elaborate a retrieval cue that will be able to trigger the reactivation of the appropriate memory trace. Finally, post-retrieval monitoring processes are run, involving the attribution of the retrieved information to a source (e.g., real *vs.* imagined event) and the verification that what is retrieved is the target episode. In order to do so, one must set a criterion which determines the characteristics that the retrieved episode must have in order to be accepted as the sought-after episode (Norman and Schacter, 1996).

For example, Schacter et al. (1996; Curran et al., 1997) have reported the case of a patient (B.G.) with damage to the right frontal lobe who produced a lot of false recognitions and classified those as remember responses when the "remember/know" paradigm was used (Gardiner, 1988; Rajaram, 1993). Encoding instructions that enhance recollection of specific information eliminated remember false recognitions, but B.G. still made a lot of false recognitions, now accompanied by know responses. Importantly, the patient did not produce any false recognition when the targets and the distractors belonged to different taxonomic categories. The nature of B.G.'s difficulty was identified as a failure to build descriptions of sought-after episodes that are focused enough (Norman and Schacter, 1996; Schacter et al., 1998). This led to an over-reliance on general characteristics common to both targets and distractors and an inability to use memory for item-specific information to overcome the familiarity felt for unstudied items. In addition, B.G. appeared to have an abnormally liberal response bias (Curran et al., 1997). A similar interpretation may account for the recognition performance of R.W., an ACoA patient described by Delbecq-Derouesné et al. (1990). This patient accepted almost as many distractors as targets in yes/no recognition memory tasks. Notably, he claimed high confidence in his errors and this chance performance occurred after semantic encoding.

By contrast, Parkin et al. (Parkin, 1997; Parkin et al, 1996, 1999; Ward, 2003; Ward and Parkin, 2000) suggested that the pathological false recognitions observed in yes/no tasks in two patients (J.B. and M.R.) with a left-sided frontal lesion was a consequence of an encoding deficit. Both patients had a normal hit rate and a great amount of false recognitions. Importantly, their productions of false recognitions were not affected by retrieval manipulations, such as taking the targets and the distractors from different categories or constraining the number of possible "yes" responses. By contrast, encoding manipulations, such as providing deep encoding instructions compared to free encoding, did improve their ability to reject distractors. Therefore, Parkin et al. (1999; Ward, 2003) and Ward and Parkin (2000) suggested that the disorder in these patients may affect the selection of the pertinent information to be encoded, leading to the creation of general memory representations which lack item-specific details.

Third, a pattern of verbal yes/no recognition memory impairment characterized by a poor hit rate and a high false recognition rate was found in a group of patients having a unilateral left frontal damage or a bilateral frontal damage (Stuss et al., 1994). In addition, their response bias did not differ from that of the controls. Stuss et al. suggested that, in these cases, this deficit could be related to either a mild residual aphasia - as evidenced by a reduced score on the Boston Naming Test - or to the fact that the damage extended to the basal forebrain, which is highly connected with the medial temporal lobe structures (see Brosutzky et al., 2000, for a review). In the former hypothesis, the mild language disorder may have interfered with the encoding of the verbal material. In the latter, the deficit may reflect an alteration of the memory processes depending on the medial temporal lobe, the damage of which is known to produce amnesia (Mayes, 2002).

Finally, Swick and Knight (1999) examined the performance of a group of patients with dorsolateral frontal lesions in a continuous yes/no recognition test and also recorded the electrophysiological neural activity of the patients during the memory test. The behavioral results indicated that the frontal patients had an increased false recognition rate, together with a normal hit rate. Moreover, their response bias was abnormally liberal. In addition, the patients as well as the controls did show event-related potential modulations which have been associated with memory retrieval, and more particularly with recollection (Düzel et al., 1997; Smith, 1993). As the event-related potential effect was normal in the frontal lobe patients, Swick and Knight suggested that the memory retrieval process itself was preserved. They proposed that the pattern of recognition memory impairment observed in these patients, with increased false recognitions and a shift in the response criterion, was a consequence of impaired strategic post-retrieval processes, by reference to the notion of a prefrontal *working-with-memory system* (Moscovitch, 1992) which monitors the products of the memory retrieval processes.

To sum up, following frontal lobe damage, yes/no recognition memory can be impaired for different reasons: an over-reliance on familiarity, a difficulty to build a description of the to-be-retrieved episode containing item-specific information, an impaired selection of appropriate information during the encoding phase or an excessively liberal response bias. In addition, it appeared that a deficit in recognition memory can occur after lesions to the dorsolateral prefrontal cortex (Swick and Knight, 1999; Schacter et al., 1996), the medial parts of the frontal lobes (R.W., Delbecq-Derouesné et al., 1990) and the basal forebrain (Stuss et al., 1994).

Recently, Verfaellie et al. (2004) have shown that different patterns of yes/no recognition memory performance after frontal lobe damage were related to different behavioral and brain damage characteristics. Verfaellie et al. (2004) measured general memory abilities of a group of 36 patients by means of the Recognition Memory Test of Warrington (1984). In addition, the patients and a group of controls performed a verbal yes/no recognition task. In this task, the study list consisted of words from various semantic categories and the number of words belonging to a category varied from 1 to 8. Verfaellie et al. (2004) found that, in the controls, this manipulation affected the contribution of recollection of item-specific details during the recognition test. Indeed, recollection, which was measured by the ability to discriminate target words from distractors belonging to studied categories, was greater when the related distractors came from categories with one studied exemplar than when they came from categories with several studied exemplars. Further, the results revealed that the 11 patients who performed poorly on the Recognition Memory Test ('amnesic frontal lobe patients') had a decreased hit rate and an increased false recognition rate on the verbal yes/no recognition task, especially in the condition where normal participants relied primarily on recollection (that is, in the one-exemplar condition). Moreover, no change in the response bias was visible in these patients. Therefore, the recognition deficit of the amnesic frontal patients was interpreted as reflecting mainly an impaired memory for item-specific details. From a neuroanatomical point of view, some amnesic frontal lobe patients presented with lesions affecting the posterior ventromedial frontal region, possibly extending to the basal forebrain. Hence, the recognition memory deficit of these patients could be part of memory disorders associated with basal forebrain damage (Brosutzky et al., 2000). In the other amnesic frontal patients, left dorsolateral frontal damage was identified. In these cases, Verfaellie et al. (2004) proposed that the memory deficit could result from mild lexical or semantic impairments.

By contrast, the 25 patients who were normal on the Recognition Memory Test performed, as a group, as well as the controls on the yes/no recognition memory task. However, three of these patients produced an excessive number of false recognitions in the context of a normal hit rate and this appeared to be due to an abnormally liberal response bias. Verfaellie et al. (2004) underlined the fact that all three had left-sided damage. The authors proposed that this could reflect either material-specific hemispheric specialization of retrieval processes or the involvement of the left frontal regions in very demanding retrieval tasks (Nolde et al., 1998).

Another recent study has shown that the presence of a verbal yes/no recognition memory deficit depends on the location of the damage (Alexander et al., 2003). Among various groups of patients presenting unilateral or bilateral lesions to distinct frontal regions, only the group of patients with lesions to the left posterior dorsolateral frontal regions was impaired on yes/no recognition memory. Their recognition performance was characterized by an increased false recognition rate and a normal hit rate, together with an excessively liberal response bias. These patients were also impaired on naming and verbal fluency. Hence, Alexander et al. (2003) proposed that a mild semantic deficit may have interfered with encoding of the verbal material and with the setting of an appropriate criterion.

The present study re-examined the effects of focal frontal lesions not affecting the basal forebrain on yes/no verbal recognition memory. The rationale for the study is as follows. First, in addition to unrelated distractors, highly similar-to-the-target distractors (synonyms) were included (Parkin, 1997; Parkin et al., 1993). The interest of this procedure is that it allows a more detailed analysis of the nature of recognition errors than standard yes/no recognition tasks. More specifically, this test provides conditions that tap differently onto recollection processes. Indeed, while unrelated distractors can be rejected because they are not familiar and/or because they are not recollected, recollection becomes crucial in the presence of the synonyms. In fact, synonym distractors may seem familiar because of their semantic relatedness to the targets, and so remembering the encoding episode is necessary to avoid false recognitions. With this task, Parkin et al. (1993, 1999) have been able to show dissociation in the performance of various frontal patients (e.g., one patient showed increased false recognitions to synonyms, a pattern interpreted as resulting from a specific recollection difficulty, Parkin et al., 1993; the profile of another patient who made a lot of false recognitions to synonyms and unrelated distractors was interpreted in terms of a reliance on a poorly focused memory description, Parkin et al., 1999).

Second, in addition to hit rates and false recognition rates for each type of distractors, we measured sensitivity and response bias by means of signal detection d' and c measures (Macmillan and Creelman, 1991). This provides additional information on the discrimination ability of the subjects as a function of the type of distractors, and on the response criterion they used.

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Third, we combined group and individual analyses of the performances observed. Therefore, in addition of looking at the performance of frontal patients as a group, we aimed at exploring whether there was any variability within cases and whether particular patterns of recognition performance could be related to particular lesion sites. More specifically, we adopted an approach consisting in grouping the patients according to their pattern of performance on the task and in looking for characteristics of the subgroups in terms of location of the lesions (Stuss et al., 2003).

Following the literature review and by reference to the constructive views of episodic memory, we anticipated that several profiles of performance on the synonyms task could be identified given the specific nature of the cognitive processes required by the task. First, some patients may show poor memory for the target words and increased false recognitions for synonyms, together with no shift in the response bias. So, they may resemble some "amnesic" frontal patients described by Verfaellie et al. (2004) and Stuss et al. (1994). Those patients with lesions to the left dorsolateral prefrontal cortex failed to encode verbal material, presumably because of semantic deficits (Stuss et al., 1994). Second, several studies indicated that frontal lobe lesions (most frequently left-sided) can disrupt post-retrieval monitoring processes, and more specifically the setting of the verification criterion (Alexander et al., 2003; Curran et al., 1997; Swick and Knight, 1999; Verfaellie et al., 2004). In those cases, one expect an impairment of recognition memory marked by increased false recognitions for unrelated and related distractors and an inadequate response criterion. Third, a specific difficulty to recollect item-specific information associated with preserved familiarity-based recognition memory should lead to false recognition for synonyms, but normal hits and unrelated false recognitions rates (Parkin et al., 1993). Finally, some patients could also performed normally (Verfaellie et al., 2004).

METHOD

General Clinical and Neuropsychological Characteristics of the Subjects

Fourteen patients with lesions of the frontal lobes and 14 healthy comparison subjects were selected for this study. All the patients underwent neurosurgical intervention at the University Hospital of Tours, France, two to three weeks before the testing. Thirteen of the patients had suffered from a tumor that had been removed by surgery and one patient had suffered from the rupture of an ACoA aneurysm that had been repaired. The patients were included only if they had a lesion restricted to the frontal lobes, as observed on computed tomography (CT) or magnetic resonance (MR) scans. In no case did the macroscopic lesions identified from the neuroimaging data extend into the basal forebrain. Of the 14 patients, 12 had unilateral frontal lobe lesions (5 right and 7 left) and two had bilateral lesions. Figure 1 illustrates the location and the extent of the lesions for each patient, as reconstructed from CT or MR scans following the atlas of Damasio and Damasio (1989). The patients had no known history of other medical diseases likely to affect cognition or to interfere with participation in the study, such as psychiatric disorders, dementia or alcoholism. The patients' mean age was 51.14 years old (range = 20-73; see Table I).

The fourteen normal comparison subjects were matched to the frontal patients on a one-to-one basis with respect to gender, age [$t(26) = -.10$, $p > .92$] and socio-economic level [$t(26) = .46$, $p > .65$].

Both the frontal brain-lesioned patients and the comparison group performed the Mattis Dementia Rating Scale (Mattis, 1973). The frontal patients were impaired compared to the normal subjects on a frontal index, due to poorer performance on the Verbal and Motor Initiation subtest [$t(26) = -2.94$, $p < .01$], and a marginal impairment on the Concepts subtest [$t(26) = -2.05$, $p < .06$], but they were normal on the other subtests (see Table II).

On tests measuring executive functioning, frontal brain-lesioned patients' performance was impaired relative to that of comparison subjects (see mean scores and standard deviations in Table II). On the Wisconsin Card Sorting Test (Nelson, 1976), the patients achieved fewer categories [$t(26) = -3.09$, $p < .01$], and made more perseverative errors [$t(26) = 3.86$, $p < .01$]. On semantic and phonemic verbal fluency (Cardebat et al., 1990), they produced significantly fewer correct responses than the normal subjects [semantic: $t(26) = -5.16$, $p < .01$; phonemic: $t(26) = -7.4$, $p < .01$]. Finally, on the Stroop test (Stroop, 1935), the patients were slower than the comparison subjects in the naming condition [$t(26) = 4.33$, $p < .01$], and in the interference condition [$t(26) = 3.06$, $p < .01$], but not in the reading condition [$t(26) = 1.81$, $p > .08$]. However, there was no difference between both groups on the interference index, calculated by the formula (interference time x naming time)/(interference time + naming time) [$t(26) = -.08$, $p > .94$].

Regarding errors in the naming and reading conditions, most of the patients and all the comparison subjects did not make any errors (two patients made respectively one and two errors in the naming condition and three patients made one error in the reading condition). In the interference condition, there were more uncorrected errors in the frontal lobe group than in the comparison group [$t(26) = 2.32$, $p < .05$].

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Fig. 1 - *Reconstruction of the lesions from CT and MR scans.*

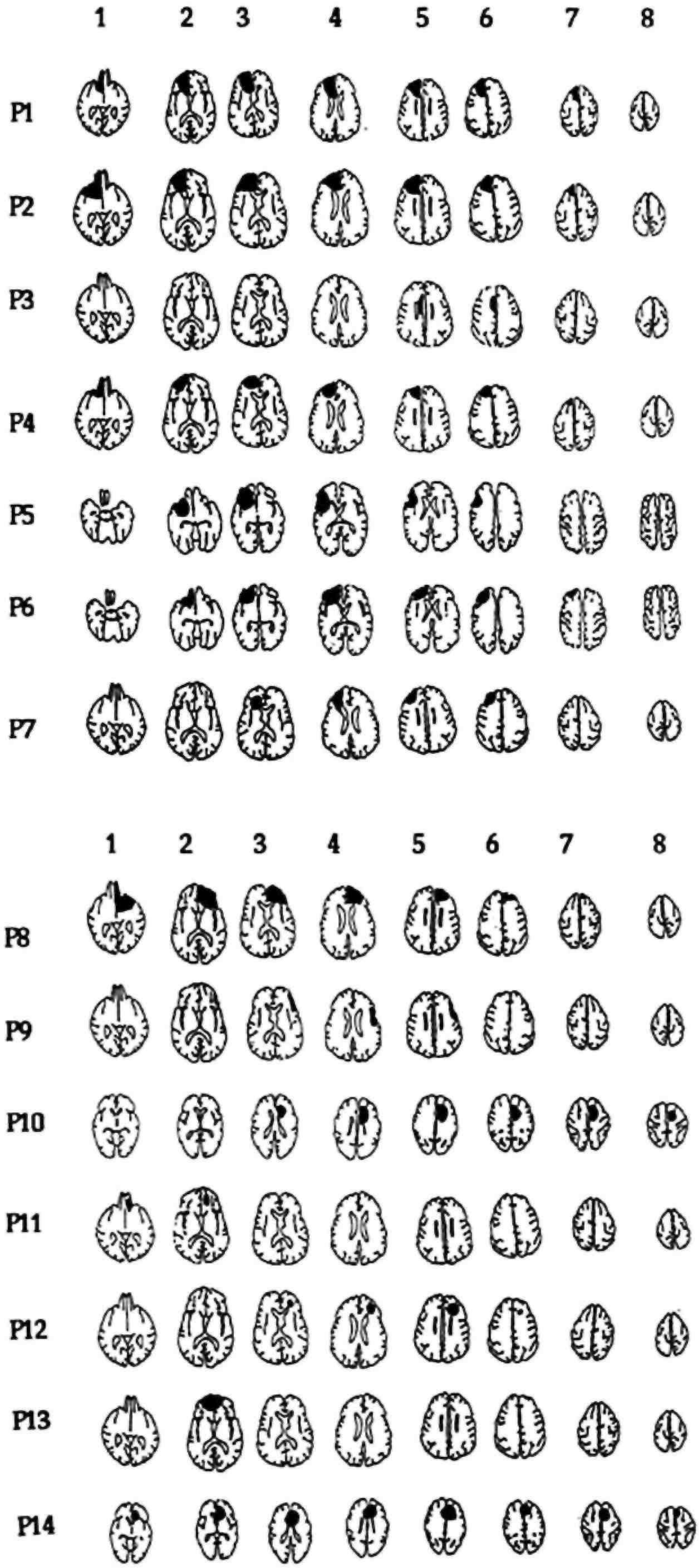

TABLE I *Characterization of the frontal lobe patients*

Patients	Lesion side	Etiology	Age	Sex	Handed-ness	Socio-economic level[3]
P1	Left	Tumor	37	F	Right	3
P2	Left	Tumor	44	M	Right	3
P3	Left	Tumor	37	M	Right	2
P4	Left	Tumor	54	F	Right	3
P5	Left	Tumor	61	M	Right	2
P6	Left	Tumor	73	M	Right	3
P7	Left	Tumor	71	F	Right	1
P8	Right	Tumor	28	F	Right	1
P9	Right	Tumor	20	F	Right	2
P10	Right	Tumor	53	F	Right	3
Pll	Right	AcoA	54	F	Right	2
P12	Right	Tumor	63	F	Left	1
P13	Bilateral	Tumor	58	F	Right	2
P14	Bilateral	Tumor	63	F	Right	3
Comparison group	-	-	51.71 ± 15.34	11 F, 3 M		2.07 ± .83

Note. [a]Socio-economic level: 1 = primary school diploma, 2 = secondary school diploma, 3 = college or university diploma.

TABLE II *Mean scores (and SD) of the frontal lobe patients and the normal comparison subjects on the Mattis Scale, the Wisconsin Card Sorting Test, the Verbal Fluency Test and the Stroop Test*

	Frontal lobe patients	Comparison Subjects
Mattis Scale		
Global score	127.21 (9.14)	135.14 (5.60)*
Attention	35.43 (.85)	36 (1.18)
Verbal and motor initiation	29.64 (5.17)	34.14 (2.48)**
Construction	6 (0)	6 (0)
Concepts	32.93 (3.50)	35.28 (2.49)
Memory	23.21 (2.01)	23.64 (1.45)
Frontal index[3]	62.57 (7.50)	70.92 (2.99)**
Wisconsin Card Sorting Test		
Number of categories	3.94 (1.59)	5.64 (1.34)**
Perseverative errors	1.5 (1.45)	o**
Phonemic fluency[b]	25.79 (10.11)	57.36 (12.36)**
Semantic fluency[c]	39.50 (10.50)	61.28 (11.40)**
Stroop Test		
Naming time (score in sec)	95.43 (27.81)	62.00 (7.86)*
Naming errors	.21 (.58)	0
Reading time	66.78 (23.63)	54.21 (10.93)
Reading errors	.21 (.42)	0
Interference time	191.57 (89.31)	117.43 (15.86)*
Interference errors	4.86 (7.59)	14 (.36)*
Interference index[d]	.31 (.17)	.31 (.06)

Note. [a]Frontal index: sum of scores at verbal-motor initiation and concepts. [b]Total number of words for letters P, R and V. [c]Total number of exemplars of animals, furniture and fruits, interference index = Interference -naming/Interference + naming. *p < .05; **p < .01

TABLE III *Mean recognition accuracy (and SD) for the frontal lobe patients and the comparison subjects on the Synonyms Distractor Task*

	Frontal lobe patients	Comparison subjects
Hits	.72 (.17)	.90 (.11)
False recognitions	.19 (.17)	.04 (.03)
Synonyms	.27 (.20)	.06 (.06)
Unrelated	.11 (.17)	.03 (.03)
d'	1.70 (.60)	3.25 (.74)
c	.22 (.52)	.17 (.28)

TABLE IV *Proportions of hit and false recognition and discrimination performance as a function of the type of distractors for each frontal lobe patient*

Patient	Hits	FR synonyms	FR unrelated	d' synonyms	d' unrelated	Criterion c
Subgroup I						
P2	.63*	.38*	.04	.64*	2.08°	.24
P3	.54*	.17	.00	1.05*	2.15°	.65
P7	.63*	.21*	.00	1.14*	2.39	.47
P10	.54*	.13	.00	1.23*	2.15°	,73°
P13	.33*	.08	.04	.97*	1.31*	.99*
Subgroup II						
P1	.92	.33*	.25*	1.85	2.08°	-.43°
P4	.96	.38*	.13*	2.06	2.88	-.04
P5	.83	.75*	.58*	.28*	.75*	-.70*
P6	.88	.46*	.33*	1.28*	1.62*	-.46*
Subgroup III						
Pll	.71	.21*	.04	1.36°	2.30	.29
P12	.83	.46*	.04	1.05*	2.71	-.14
P14	.79	.25*	.08	1.48°	2.21	.07
Subgroup IV						
P8	.75	.04	.00	2.43	2.73	.69
P9	.71	.00	.04	2.61	2.30	,75°
Comparison group	.90 (.11)	.06 (.06)	.03 (.03)	3.11 (.81)	3.26 (.56)	.17 (.28)

Note. FR synonyms = false recognitions for synonyms. FR unrelated = false recognitions for unrelated distractors. *Modified *t-test* (Crawford et al., 2003) significant at p < .05 two-tailed, p < .08.

Materials and Procedure

The patients and the comparison subjects performed the synonym distractor task, which was adapted from the study by Parkin et al. (1993). The material consisted in three sets of 24 concrete nouns, matched in terms of frequency of occurrence in French (on average, 5085 occurrences per 100,000,000 - according to the Brulex database; Content et al., 1990) and length (from 3 to 13 letters). Two sets of words consisted of pairs of synonyms, with each word from the first set being a synonym of a word in the second set. One of these sets was designated as target list and the other as distractor list. The third set comprised unrelated words that served as distractors.

During the study phase, the list of 24 target words was presented visually on small cards and each word was shown for 3 seconds. Subjects were asked to try and remember the words in order to recognize them later among others. After a 10 minutes delay (during which the subjects performed the Stroop test), memory was tested by a yes/no recognition task. The test list comprised 72 words, consisting of the 24 target words, the 24 synonyms and the 24 unrelated distractors. The words were presented one by one, on cards. The subjects had to say for each word whether it had been presented in the study phase.

RESULTS

Group Comparisons

The proportions of hits and false recognitions for both groups are presented in Table III. The frontal patients recognized significantly fewer target words than the comparison subjects [t(26) = - 3.38, p < .01]. An ANOVA on proportion of false recognitions as a function of the Type of Distractors (synonyms *vs.* unrelated) and Group (frontal lobe patients *vs.* comparison group) indicated that the frontal lobe group globally made more false

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recognitions than the comparison subjects [F (1, 26) = 9.67, p < .01] and that false recognitions were more frequent for synonyms than for unrelated distractors [F (1, 26) = 26.41, p < .01]. The significant interaction [F (1, 26) = 14.54, p < .01] showed that the frontal lobe patients made more false recognitions on synonyms than on unrelated distractors (p < .01), whereas the normal subjects falsely recognized as many synonyms as unrelated distractors (p > .36). In addition, the frontal lobe patients produced significantly more false recognitions for synonyms than the comparison group (p < .01), whereas the difference was only marginal for the unrelated distractors (p < .10).

Global discrimination performance was calculated by means of *d'* scores on the basis of hits and false recognitions (Macmillan and Creelman, 1991) and appeared to be poorer in the frontal group than in the comparison group [t(26) = -6.11, p < .01] (see Table III). Moreover, the two groups did not differ regarding response bias (criterion c, Macmillan and Creelman, 1991) [t(26) = .33, p > .74]. The ability to discriminate between the targets and the synonyms was measured by the *d'* scores calculed on the basis of the hits and the false recognitions for synonyms *(d' synonyms),* whereas the ability to discriminate between the targets and the unrelated distractors was measured by the *d'* scores based on the hits and the false recognitions for unrelated words *(d' unrelated).* The first measure *(d' synonyms)* should reflect a type of discrimination that is more strongly based on recollection than the second measure *(d' unrelated).* An ANOVA on these scores as a function of the group confirmed that global recognition accuracy was poorer in the frontal group [F (1, 26) = 38.98, p < .01] and that the subjects discriminated better between targets and unrelated distractors than between targets and synonyms [F (1, 26) = 23.14, p < .01]. Moreover, the interaction [F (1, 26) = 9.95, p < .01] showed that the frontal patients were particularly poor at discriminating between targets and synonyms (mean = 1.39), compared to unrelated distractors (mean = 2.12, p < .01), whereas comparison subjects were not affected by the type of distractors *(d' synonyms:* mean = 3.11; *d' unrelated:* mean = 3.26, p > .25). Moreover, the frontal group showed impaired discrimination ability on both scores (ps < .01).

Variability in Performance in the Frontal Lobe Patients

Hit and False Recognition Rates

We compared the performance of each frontal lobe patients (see Table IV) to the comparison group's mean by calculating the modified t-test developed for single-case studies (Crawford and Garthwaite, 2002; Crawford et al., 2003). The comparison group's mean could be used as a reference, although the comparison subjects differed from each other in terms of age, because their performance did not correlate with age (all ps > .18 on the different measures). The patient was considered as impaired on a score if his or her performance was significantly poorer than that of the comparison subjects when the alpha level was set at .05 (two-tailed).

It appeared that the patients could be divided into two subgroups according to their hit rate: 5 patients (P2, P3, P7, P10 and P13) recognized fewer targets than the comparison subjects and 9 patients (P1, P4, P5, P6, P8, P9, Pll, P12, and P14) had a normal hit rate. Furthermore, within each of these groups, there was some variability in the false alarm rates. Among the 5 patients with impaired hit rate (subgroup I), 2 patients (P2 and P7) falsely recognized synonyms more often than the comparison subjects, but did not differ from the comparison group regarding the false recognitions to unrelated distractors. The remaining 3 patients (P3, P10 and P13) produced the same number of false recognitions as the comparison group. However, it should be noted that they produced numerically more false recognitions for synonyms than for unrelated distractors.

Among the 9 patients with a normal hit rate, 4 patients (P1, P4, P5, and P6) had a pathological false alarm rate for synonyms as well as for unrelated distractors (subgroup II). Three patients (Pll, P12, P14) made a lot of false recognitions for synonyms, but not for unrelated distractors (subgroup III). The other 2 patients (P8 and P9) did not produce more false recognitions than the comparison subjects, and thus performed completely normally on the task (subgroup IV).

Discriminability Scores and Response Bias

The 5 frontal lobe patients who had a decreased hit rate (subgroup I, see Table IV) presented an impaired ability to discriminate between targets and synonyms *(d' synonyms).* As for the discrimination between targets and unrelated distractors *(d' unrelated),* it was clearly impaired in patient P13, but only marginally impaired in P2, P3 and P10 and unimpaired in P7. The response bias did not significantly differ between most of these patients and the comparison subjects, with the exception of P13 whose criterion appeared more conservative than that of the comparison group. The criterion was also marginally more conservative in P10.

Among the 4 patients who showed a normal hit rate and an increased false recognition rate (subgroup II), discrimination between targets and both types of distractors was impaired on 2 patients (P5 and P6) and preserved in the other 2 (P1 and P4). In P1, however, the *d' unrelated* scores appeared marginally lower than in the comparison subjects. Moreover, the response bias was excessively liberal in P5 and P6 and tended to be too liberal in P1. But there was no shift in the response bias in P4.

The three patients with a normal hit rate and a pathological number of false recognitions for synonyms (subgroup III) had lower ability to discriminate between targets and synonyms (the difference was marginally significant for Pll and P14). None of them showed impaired ability to discriminate between targets and unrelated distractors. Moreover, their response bias did not differ from that of the comparison group.

Finally, as already observed with the hits and false recognitions, P8 and P9 (subgroup IV) had normal discrimination scores. In addition, P8 had the same response bias as the comparison subjects, whereas P9 tended to be more conservative.

Comparisons of the Subgroups on Neuropsychological Measures and Age

Compared to the other patients, the patients in subgroup I (showing impaired hit rate) did not differ in terms of age ($U = 21.5$, $Z = -.13$, $p > .89$), performance to the Mattis ($ps > .23$) or performance on the various executive tests ($ps > .23$). Similarly, the patients with a normal hit rate and a high number of false recognitions for both types of distractors (subgroup II) did not differ from the others with respect to age or neuropsychological measures.

As for the three patients who made false recognitions for the synonyms only (subgroup III), they produced more items in the semantic and phonemic fluency tasks than the others (semantic: mean = 53.67, other patients = 35.64, $U = .5$, $Z = -2.49$, $p < .05$; phonemic: mean = 37.67, other patients = 22.54, $U = 2$, $Z = -2.26$, $p < .05$). Actually, this was the only subgroup to perform normally on the semantic fluency task ($U = 10.5$, $Z = 1.32$, $p > .18$) There were no other differences.

Finally, the two patients who performed normally (subgroup IV) were younger (mean = 24 years old) than the others (mean = 55.67; $U = 0$, $Z = 2.19$, $p < .05$) and responded more quickly to the naming condition of the Stroop test (mean = 66.5 sec; other patients: mean = 100.25; $U = .5$, $Z = 2.10$, $p < .05$). In addition, they performed similarly to the other patients on the other neuropsychological measures.

Comparisons of the Subgroups in Terms of Location of the Brain Damage

The location of the lesions in each patient is presented in Table V. It appears that within each subgroup, the patients tended to have similar types of lesions, at least in terms of lateralization.

Among the patients with an impaired hit rate (subgroup I), the damage was left-sided in three patients, bilateral in one patient, and right-sided in another one. Interestingly, all the patients in subgroup II (presenting with normal hit rate and increase of false recognitions for both types of distractors) had left-sided lesions. Moreover, the damage involved the orbital gyrus, the fronto-polar region, the inferior frontal gyrus and the middle frontal gyrus in all of them.

The patients with a high number of false recognitions for synonyms only (subgroup III) had right-sided lesions (except for P14 whose damage was bilateral)[1], as well as the two patients who performed normally on the task (subgroup IV).

TABLE V *Location of the lesion of the frontal lobe patients*

Patients	Orbital gyrus	Anterior cingulated cortex	Fronto-polar region	Inferior frontal gyrus	Middle frontal gyrus	Superior frontal gyrus	
						Medial part	Lateral part
I. Impaired hit rate							
P2	L	L	L	L	L	L	L
P3		L					
P7				L-	L		L
P10		R				R	R-
P13	B	B-	B	B			
II. Normal hit rate and increased false recognitions for synonyms and unrelated distractors							
P1	L	L	L	L	L	L	L
P4	L	L	L	L	L	L	L
P5	L-		L-	L	L		
P6	L	L-	L	L	L		L
///. Normal hit rate and increased false recognitions for synonyms							
Pll	R						
P12		R-		R	R-		
P14		B				B	R
IV. Normal recognition memory							
P8	R	R	R	R	R	R	R
P9				R	R		

Note. L = left hemisphere. R = right hemisphere. B = bilateral. - = partial lesion of the gyrus.

DISCUSSION

The present study examined recognition memory performance in a group of frontal lobe patients. First of all, the group analysis confirmed that frontal lobe lesions can induce a deficit of recognition memory, as suggested by previous studies (Delbecq-Derouesné et al., 1990; Parkin et al., 1994, 1996; Schacter et al., 1996; Swick and Knight, 1999; Verfaellie et al, 2004). As a group, the frontal patients recognized correctly fewer targets than the comparison subjects. In addition, they made more false recognitions than the comparison group, especially for unstudied words that were synonyms to the targets. Because synonyms can appear strongly familiar, the comparison subjects probably recollected specific information about the targets in order to reject the synonyms (Dobbins et al., 1998) to a greater extent than when rejecting the unrelated distractions. The performance of the frontal patients suggests that they failed to use recollection of specific details.

As expected, several subgroups could be distinguished on the basis of the hit and false recognition rates of the patients. Five patients had a decreased hit rate, combined with a tendency to produce more false recognitions for synonyms (subgroup I). Four patients had a normal hit rate,1t should be noted that, in subgroup III, one of the patient (P12) was a lefthander, but she had a profile of performance comparable to the other patients of the subgroup. but increased false recognition rate for both types of distractors (subgroup II). Three patients had the same hit rate as the comparison subjects, but an excessive number of false recognitions for synonyms only (subgroup III). Finally, two patients performed normally (subgroup IV).

In subgroup I, memory for the targets appeared to be poor. The fact that these patients failed to discriminate between targets and synonyms suggests that they were unable to use recollection of specific details and were only left with familiarity to recognize the items. In most of them, the ability to discriminate between targets and unrelated distractors tended to be impaired, possibly as a consequence of deficient recollection. In addition, the response bias of these patients did not differ from that of the comparison subjects, except for P13. But the more conservative response criterion of this patient seems to result from her very low hit rate. These patients thus resembled the amnesic frontal lobe patients described by Verfaellie et al. (2004), who had an impaired hit rate and a particularly high number of false recognitions in a condition where normal subjects relied primarily on recollection to discriminate between targets and related distractors.

The patients in subgroup I contrasted with the three patients who also produced many false recognitions for synonyms, but in the context of normal hit rate (subgroup III). Examination of the lesion sites revealed that the lateralization of the lesion could at least partly be responsible for the distinct patterns of recognition impairment observed in these two subgroups. Indeed, in subgroup I, four patients out of five had a damage affecting the left frontal lobe. By contrast, in subgroup III, the damage was right-sided in two of the patients and bilateral in the third one. A chi-square analysis on the contingency table based on the number of left- *vs.* right-sided lesions in subgroup I and III showed a significant difference $\chi^2 = 5$, $p < .05$). Further, a direct comparison of the two subgroups indicated that the patients in subgroup I had lower verbal fluency performance than the patients in subgroup III (ps < .05). Therefore, it may be that the patients who had an impaired hit rate (subgroup I) presents with difficulties to retrieve information from semantic memory. Such difficulties may in turn lead to impoverished encoding of verbal material in episodic memory (Tulving et al., 1994), resulting in poor memory for the targets. By contrast, the patients with a normal hit rate and increased false recognitions for synonyms (subgroup III) may have, following damage to the right frontal lobe, a specific difficulty of episodic memory retrieval, preventing them from recollecting item details. This would be consistent with the idea that the retrieval of information in episodic memory depends on the right frontal regions (Nyberg et al., 1996; Tulving et al., 1994). The case of patient P10 deserves some comments. P10 was the only patient in subgroup I who showed decreased memory for the targets in the context of right-sided frontal damage. We have no ready explanation for these findings. A possible interpretation could be that this patient presented with an atypical language right-hemisphere dominance, as has been found in some healthy right-handers (Knecht et al., 2000, 2001, 2003).

Some left frontal lobe patients presented with a completely different pattern from the patients in subgroup I, consisting in a normal hit rate, but a pathological number of false recognitions (subgroup II). Actually, these patients produced a lot of false recognitions for synonyms as well as for unrelated distractors. In addition, they showed a shift in their response bias. This one was excessively liberal (except for P4). Thus, the recognition memory deficit of these patients could be due to impaired strategic verification processes, affecting the setting of an appropriate criterion (Alexander et al., 2003; Curran et al., 1997; Swick and Knight, 1999; Verfaellie et al., 2004). Alternatively, they could fail to build a focused description of the sought-after memory and consequently, accept many distractors corresponding to a very general description (Schacter et al., 1996).

It should be noted that, from a functional point of view, we cannot exclude the possibility that the difficulty to reject both types of distractors in subgroup II may reflect a more severe instantiation of the deficit which lead the patients in subgroup III to falsely recognize the synonyms. However, on the basis of differences in the location of the brain damage of the patients in the two subgroups, we have considered that their profiles could reflect distinct kind of difficulties. Indeed, all the patients in subgroup II had a left-sided frontal damage and most of the patients on subgroup III had a right-sided lesion ($\chi^2 = 5$, $p < .05$).

Finally, two frontal brain-damaged patients had normal recognition memory performance. This represents a small proportion of the frontal group compared to Verfaellie et al.'s (2004) study. In the present experiment, the only points which distinguished these two patients from the others were their age (they were the two youngest patients of the group, P8 was 28 years old and P9 20) and the speed of information processing, as measured by the naming time in the Stroop. It may be that their performance was normal because it was compared to that of an older comparison group (55 years old). As aging can disrupt recognition memory, age-related poorer performance in the comparison group could have masked a deficit in P8 and P9. However, this is unlikely as, in the present comparison group, there was no correlation between age and performance in the synonym task. Moreover, the two young patients performed as well as a new group of 11 normal subjects matched to P8 and P9 in terms of age, sex and education [young comparison group (mean age: 22.45 ± 1.57), hits: .81 ± .11; false recognitions to synonyms: .16 ± .10; false recognition to unrelated distractors: .08 ± .08; *d' synonyms:* 2.01 ± .66; *d' unrelated:* 2.42 ± .69; criterion *c:* .11 ± .36, all ps > .11]. Future research should clarify whether age at the damage onset is a determinant factor for the severity of the memory disorders following focal frontal lobe lesions. The fact that P8 and P9 showed a faster processing time than the other patients may be related to their young age. Indeed, longer reaction times in the other patients, whose mean age was around 55 years old, could reflect age-related slowing of processing speed (Salthouse, 1996). Moreover, it is interesting to note that both patients had a right-sided frontal damage. It could be that having a preserved left frontal lobe is a necessary condition for achieving normal recognition performance. However, this hypothesis is not supported by the data from Alexander et al. (2003) and Verfaellie et al. (2004), who showed normal recognition memory in left frontal-lesioned patients.

It is necessary to consider some limits of this study. First, the statistical approach adopted here (Crawford and Garthwaite, 2002) is more conservative than other methods, such as the z-scores method. Although this diminishes the risk of Type I error, we acknowledge that the comparison of the present results with other reports is not straightforward. However, when a difference of 1.95 SD from the comparison group's mean was used as in previous studies (e.g., Verfaellie et al., 2004), the conclusion regarding the patients' performance remains globally similar. The only divergences are, first, that the scores which were previously marginally significant became significant. Concretely, the impairment of the *d' synonyms* of P11 and of the *d' unrelated* of P1, P2, P3 and P10 was now significant. Moreover, the response bias of P1, P9 and P10 became significantly different from that of the comparison subjects. Second, the results of two patients appeared less clear. Indeed, with the z-score method, the *d' unrelated* of P14 was marginally significant ($p < .07$) and P9 tended to recognize less target words than the comparison subjects ($p < .09$). So, if we except these two patients, the different patterns of performance demonstrated by each subgroup appeared to be solid. A second limitation concerns the size of the patient subgroups. A larger sample would be necessary to confirm statistically the qualitative differences between the subgroups. Moreover, the small number of patients and the fact that the lesions were widespread in most of them did not allow to establish relations between lesions to specific frontal subregions and particular pattern of recognition performance.

Nonetheless, the evidence demonstrating impaired recognition memory in patients with frontal lesions is still very sparse. Some factors such as lack of statistical power (Wheeler et al., 1995) and the type of recognition task used (Parkin et al., 1994) have been considered. But providing new empirical findings using the lesion method may be crucial for our theoretical understanding of the role of the frontal lobes in episodic memory. Thus, in the context of the dearth of research on subgroups of frontal patients, it is worth noting that, with the exception of P9 and P14, the other patients showed various patterns of recognition performance that appeared theoretically significant and consistent with the existing literature. In addition, the association between the patterns of recognition deficits and the lateralization of the lesions was reliable.

To sum up, some patients showed poor memory for the targets and most of them had left-sided lesions. They may have an encoding difficulty, resulting from impaired semantic processing, like the "amnesic" patients in the studies by Verfaellie et al. (2004) and Stuss et al. (1994). Another subgroup with left frontal lesions recognized as many targets as the comparison subjects, but produced a lot of false recognitions for both types of distractors. Their response bias was also abnormally liberal, suggesting impaired strategic verification processes (Alexander et al., 2003; Swick and Knight, 1999; Verfaellie et al., 2004). Finally, the recognition deficit of a last subgroup was only due to a high rate of false recognitions for synonyms. These patients thus relied mainly on familiarity and could not use recollection of specific details to reject highly familiar distractors. Their deficit could result from a specific deficit of episodic retrieval, associated with right prefrontal lesions. Although the lateralization of the lesion may contribute to the production of these different types of difficulty, further research should be conducted in order to identify potential demographic and/or cognitive variables that could interact with the frontal damage in order to produce each of these patterns.

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