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EVIDENCE FOR A POSSIBLE NEUROANATOMICAL BASIS FOR LEXICAL PROCESSING OF NOUNS AND VERBS

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Abstract—Neuropsychological studies have revealed that brain-damaged patients may show impairments of specific word categories. This study reports the performance of three patients with impairments of the categories noun and verb. The first and second patients, with left frontal lobe atrophy, were impaired in naming and comprehension of verbs. The third patient, with striking atrophy of the left temporal lobe, was disproportionately impaired in naming and comprehension of nouns. These findings suggest that anatomically distinct neural systems in the temporal and frontal lobes of the dominant hemisphere might play a critical role in lexical processing of nouns and verbs, respectively.

Key Words: anomia; aphasia; category-specific deficits; grammatical-class impairments; semantics.

INTRODUCTION

Several neuropsychological investigations have shown that brain-damaged patients may demonstrate selective impairments of specific lexical–semantic categories, such as abstract vs concrete words [59, 60, 63], proper nouns [39, 51], body parts [20, 50], living things vs inanimate objects [1, 8, 25, 38, 49, 55, 56, 61, 63]. Moreover, a number of studies have described possible further fractionations within the broad categories of living things and inanimate objects, thus suggesting a fine-grain categorical organization of semantic knowledge [62]. So far, selective impairments of the categories fruits and vegetables [29], animals [30, 31], "indoor" objects and body parts [66], small manipulable objects [62], artefactual objects and body parts [48] have been reported. These patterns of deficits support the view that semantic knowledge is organized by categories [31, 52, 62, 63] and suggest that there may be dissociable neural systems critical for knowledge of different lexical and semantic categories [7, 22, 35, 62, 63]. Nonetheless, the importance of controlling for relevant factors that could affect performance in studies reporting category-specific impairments has been recently pointed out [21, 58].

Category-specific deficits have also been described for grammatical classes of words, such as nouns and verbs. Selective impairments in the production and comprehension of nouns have been reported in anomic aphasic patients, while selective impairments of the category

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verb have also been documented, mostly in agrammatic aphasic patients [2, 5, 24, 37, 41, 42, 67, 68]. In particular, Caramazza and Hillis [5] have reported two patients who were impaired in producing only the verb form of homonymic words (such as the word *crack*, that has both a noun and verb form), in oral and written modality, respectively. This finding demonstrates that their deficit did not concern specific lexical forms, but the grammatical-class verb. The contrasting patterns of modality-specific grammatical-class impairments reported for the two patients suggest that grammatical-category information is represented redundantly in lexical components involved in spoken and written production. In conclusion, various studies have convincingly shown that the lexical system is organized by grammatical class [3].

Previous investigations, however, have not focused on possible anatomical bases for grammatical-class impairments, probably because the available localizing information had not allowed unambiguous inferences to be drawn, particularly as regards selective impairments of verbs. Selective impairments of the category noun had been observed in patients with brain lesion either confined to the temporal lobe [41, 42] or variously encompassing other cerebral regions as well [41, 42, 67, 68]. On the other hand, until recently, selective impairments of the category verb had been reported in single-case studies of patients with quite extensive brain damage, involving two to three cerebral lobes [2, 5, 42], or with cortical atrophy [38].

Lately, Damasio and co-workers hypothesized the existence of two-way-access systems that mediate between concepts and word forms [11, 13], proposing that such mediation systems for entities denoted by proper nouns are likely to be located in the left temporal pole, while mediation systems for certain categories of natural entities denoted by common nouns are located in the left lateral and inferior temporal regions [9–12]. On the other hand, on the basis of preliminary evidence, Damasio and co-workers suggested that mediation systems for verbs could be located in frontal and parietal sites [13, 14], concluding that further investigations, either of aphasic patients or of normal subjects, were needed in order to better clarify the anatomical arrangement of the mediation systems for verbs [13].

More recently, Damasio and Tranel [15] have provided a significant contribution to this issue, describing three brain-damaged patients with a double dissociation between noun and verb retrieval. Patients Boswell and AN-1033, who had lesions in the left anterior and middle temporal lobe, showed a selective deficit in noun retrieval. On the other hand, patient KJ-1360, who had a left premotor lesion, showed a selective verb-retrieval deficit. Damasio and Tranel [15] have suggested that mediation systems for the retrieval of nouns that denote concrete entities are in the left anterior and middle temporal cortices, while equivalent mediation systems for verb retrieval are in the left frontal region.

These findings were in good agreement with some observations that we had previously reported on three brain-damaged patients with category-specific deficits for grammatical-class knowledge [16–18], in order to provide more definite evidence for neuroanatomical correlates of impairments of the categories noun and verb. One patient, with left temporal lobe atrophy, showed a disproportionate impairment in naming and comprehension of nouns. In two patients, with left frontal lobe damage, a selective impairment in naming and comprehension of verbs was documented. Accordingly, we proposed that distinct neural systems in the temporal and frontal lobes of the dominant hemisphere might play a critical role in lexical mechanisms involved in production and comprehension of nouns and verbs, respectively [17, 18].

In the present paper, we more extensively describe the three brain-damaged patients with

grammatical-class impairments we had investigated and preliminarly reported. Moreover, we critically review the literature relevant to the issue of the neuroanatomical correlates of category-specific deficits for grammatical-class knowledge. All three patients underwent neuroimaging investigation, including magnetic resonance imaging (MRI) and single photon emission computed tomography (SPECT). MRI was carried out with a 1.5 tesla scanner, using T1-weighted and T2-weighted spin-echo pulse sequences. Measurements of regional cerebral blood flow (rCBF) were obtained by means of SPECT using 99m tecnectium-d,l-hexamethyl-propylen-amin-oxim (99m Tc HM-PAO) as a tracer. Moreover, our patients underwent neuropsychological assessment and were given experimental lexical–semantic tests on both nouns and verbs, matched for word frequency and length. These latter tests were partly modified versions of the Object and Action Naming and Comprehension tests [42] and were partly drawn from a preliminary version of the Battery for the Analysis of Aphasic Deficits [43].

CASE REPORTS

Case 1

R.A., a 67-year-old right-handed housewife, presented with a 2-year history of progressive language deterioration, due to a focal degenerative pathology [40, 64]. At the age of 65 years, she started to experience word-finding difficulty and complained of problems pronouncing words. At first, her comprehension of spoken and written language was apparently intact. Insight, judgement and effectiveness in most activities of daily living were initially unaffected. On admission, neurological examination was unremarkable, apart from a right-sided grasp reflex. Over the successive examinations, patient R.A. progressively developed striking clinical manifestations of frontal lobe damage (apathy, mutism, utilization [33, 54] and perseverative behaviours, *gegenhalten*, predominantly right-sided grasp reflex). Routine laboratory investigations were normal.

Neuroimaging findings. MRI showed marked atrophy of the posterior regions of the frontal lobes, mainly involving the posterior parts of the medius and inferior frontal gyri of the left cerebral hemisphere (Fig. 1a). On T2-weighted images, there were small areas of increased signal intensity in the corona radiata frontalis. A 99m Tc HM-PAO SPECT showed a restricted perfusion abnormality in the left frontal regions (Fig. 1b).

Neuropsychological testing. In the initial examination, patient R.A. performed within the normal range on tests of visual memory, ideomotor and constructional apraxia and on Raven's Progressive Matrices [47]. On the other hand, she was severely impaired on tasks sensitive to frontal lobe dysfunction (Wisconsin Card Sorting Test [27], verbal fluency). In addition, patient R.A. was mildly impaired on free recall verbal memory tasks and showed mild oral apraxia.

Spontaneous speech was nonfluent, grammatical, with occasional articulatory errors and verb-finding pauses. On admission, her performance on tests of oral confrontation naming of objects was relatively good, with only occasional omissions and semantic errors. Tasks of phonemic discrimination, auditory and visual lexical decision and word–picture matching were performed quite accurately. Comprehension of aurally and visually presented sentences was slightly impaired, mainly on reversible sentences. Repetition of words and nonwords was accurate. On reading and writing-to-dictation, she had greater difficulty with nonwords than words. On these latter tasks, no grammatical-class effect was found.

Experimental investigation. Patient R.A. was given experimental lexical semantic tasks on nouns and verbs across three sessions* (Table 1). In the first and second sessions, she was given Oral and Written Confrontation Naming tasks [43], on which she was asked to name line drawings depicting objects and actions. In both sessions, patient R.A. performed within normal limits in oral and written naming of nouns. By contrast, she showed considerable difficulties in naming verbs. In particular, in the first session (December 1988), a significantly greater impairment in the production of verbs than of nouns could be detected only on the Written Confrontation Naming task. In the second session (April 1989), a selective impairment in naming verbs was observed on both the Oral [42] and Written [43] Confrontation Naming tasks. In the first and second sessions, on both oral and written naming, various types of errors were observed on verbs (verb nominalizations, omissions, circumlocutions and semantic errors), while the few errors on nouns consisted of semantic ones and omissions. Occasional articulatory errors on oral naming and spelling errors on written naming were ignored and are not reported in Table 1. Patient R.A. was generally able to give appropriate definitions about the items that she could not name. In the second session, she performed relatively well on Auditory and Visual Lexical Decision tasks [43]. In both tasks the stimuli consisted of 40 words (10 nouns, 10 verbs, 10 adjectives, 10 function words) and 40 nonwords; order of presentation was randomized across all stimuli. On both Lexical Decision tasks, no significant grammatical-class effect was observed. On a Word Picture Matching task [42], the patient was given a spoken target-word (either a noun or a verb) and three pictures corresponding to the target-word, a semantically-related distractor and a non-related distractor, respectively. On this latter task, in the second session, patient R.A. performed flawlessly on nouns and a statistical trend towards a lower accuracy in comprehension of verbs was observed. In a third session (March 1990), the patient had developed marked mutism, showing remarkable difficulties in tasks requiring speech production. Thus, she was no longer initiating conversation and her speech was limited to infrequent noun phrases. On this occasion, patient R.A. had severe difficulty in performing the Oral Confrontation Naming task [42], on which she often produced no response. In this latter task, nonetheless, a significantly greater impairment in the production of verbs was observed. On a shortened version of the Word–Picture Matching task [42], patient R.A. was relatively accurate in the comprehension of nouns, while she showed a significantly greater difficulty in the comprehension of verbs, making only semantically-related errors.

Case 2

G.G., a 57-year-old right-handed clerk, at the age of 55 years started to experience slurring of speech and writing difficulties. In addition, he was noted to become increasingly apathetic and irritable. Progressive walking difficulty, slowness, backward falls, swallowing difficulties then appeared. Neurological examination revealed a mild supranuclear vertical gaze palsy, blepharospasm, moderate dysarthria, axial rigidity and bradykinesia. A right-sided palmomental reflex was also present. These clinical features were consistent with a diagnosis of probable Steele–Richardson–Olszewski (SRO) syndrome or progressive supranuclear palsy [23]. Routine laboratory investigations were normal.

Neuroimaging findings. MRI showed moderate atrophy of the posterior regions of the left frontal lobe (Fig. 1c). There were also small areas of increased signal intensity in the left corona radiata frontalis on T2-weighted images. A 99m Tc HM-PAO SPECT showed a restricted perfusion abnormality in the left frontal regions (Fig. 1d). A similar pattern of decreased regional cerebral blood flow in the frontal regions has been documented in patients with the SRO syndrome by positron emission tomography (PET) studies [19, 32].

Neuropsychological testing. Patient G.G. performed within the normal range on tests of visual memory, oral, ideomotor and constructional apraxia and on Raven's Progressive Matrices [47], while he was mildly impaired on free recall verbal memory tasks. His performance on a number of visual perception and cancellation tasks was remarkably accurate. On the other hand, patient G.G. performed poorly on tasks sensitive to frontal lobe

*The scores obtained by 20 normal control subjects on the various experimental tasks on nouns and verbs are reported below as mean percent correct and standard deviations. These tasks included an Oral Confrontation Naming task (42) (nouns = 98.2 ± 2.0; verbs = 95.4 ± 3.7), a Word–Picture Matching task [42] (nouns = 99.9 ± 0.5; verbs = 99.9 ± 0.5), an Oral Confrontation Naming task [43] (nouns = 97.3 ± 2.8; verbs = 97.3 ± 2.9), a Written Confrontation Naming task [43] (nouns = 97.9 ± 2.5; verbs = 96.7 ± 2.8), an Auditory Lexical Decision task [43] (words = 99.7 ± 0.5; nonwords = 98.7 ± 1.7), and a Visual Lexical Decision task [43] (words = 99.9 ± 0.8; nonwords = 98.0 ± 2.4).

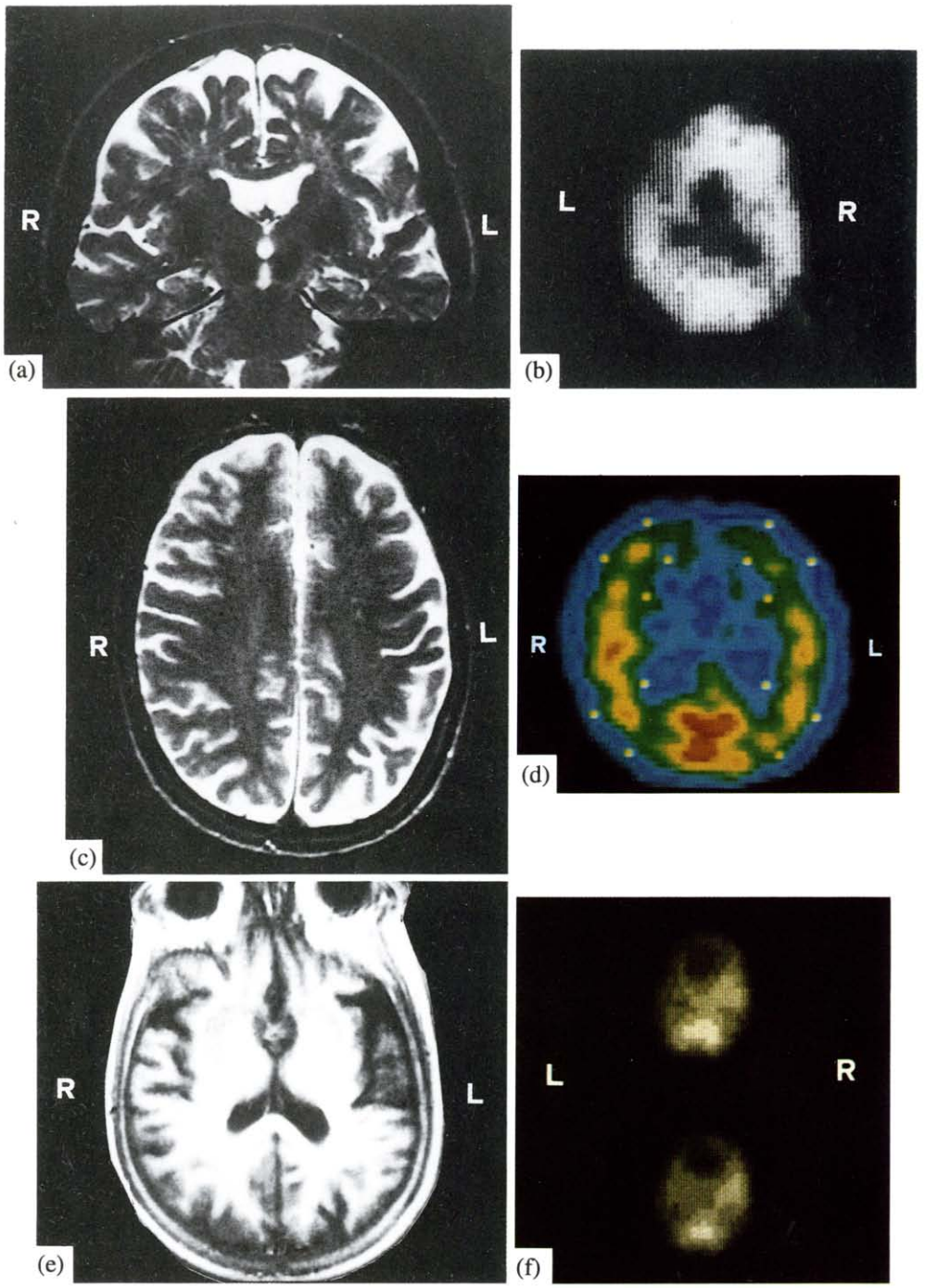

Fig. 1. Neuroimaging findings. (a) Patient R.A.: coronal T2-weighted MRI (December 1988). Marked cortical atrophy of the posterior regions of the frontal lobes, mainly involving the medius and inferior frontal gyri of the left hemisphere. Small areas of increased signal intensity in the corona radiata frontalis. Enlargement of Virchow–Robin's spaces. (b) Patient R.A.: 99m Tc HM-PAO SPECT (February 1989). Reduction in rCBF restricted to the frontal regions of the left hemisphere (10% of interhemispheric asymmetry). (c) Patient G.G.: axial T2-weighted MRI (July 1991). Moderate atrophy of the posterior regions of the left frontal lobe. (d) Patient G.G.: 99m Tc HM-PAO SPECT (July 1991). Reduction in rCBF restricted to the frontal regions of the left hemisphere (14% of interhemispheric asymmetry). (e) Patient G.P.: axial T1-weighted MRI (December 1988). Striking cortical and subcortical atrophy of the left temporal lobe, more evident in the anterior temporal regions. (f) Patient G.P.: 99m Tc HM-PAO SPECT (January 1989). Marked reduction in rCBF in the temporal regions of the left hemisphere (39% of interhemispheric asymmetry).

Table 1. Performance of patient R.A. across experimental tasks on nouns and verbs. The total number of stimuli (N) is reported for each task. Not significant: n.s.

	Nouns		Verbs			
	N	Errors (%)	N	Errors (%)	P	
First session						
Oral Confrontation Naming	30	7	36	19	n.s.	Fisher's test
Written Confrontation Naming	24	0	29	24	0.01	Fisher's test
Second session						
Oral Confrontation Naming	48	4	48	35	<0.001	$\chi^2 = 14.8$
Written Confrontation Naming	24	8	29	48	0.002	$\chi^2 = 9.1$
Auditory Lexical Decision	10	10	10	0	n.s.	Fisher's test
Words ($N=40$): Errors = 2%						
Nonwords ($N=40$): Errors = 2%						
Visual Lexical Decision	10	0	10	10	n.s.	Fisher's test
Words ($N=40$): Errors = 7%						
Nonwords ($N=40$): Errors = 2%						
Word–Picture Matching	48	0	48	8	0.06	Fisher's test
(1 spoken word–3 pictures)						
Third session						
Oral Confrontation Naming	48	69	48	96	<0.001	$\chi^2 = 12.1$
Word Picture Matching	24	4	24	25	0.04	Fisher's test
(1 spoken word–3 pictures)						

dysfunction (Wisconsin Card Sorting test [27], verbal fluency). These latter tasks, according to various studies, are particularly impaired in patients with the SRO syndrome [26, 34, 46].

His spontaneous speech was nonfluent, grammatical, with articulatory errors and occasional word-finding difficulties. Patient G.G. performed quite accurately on tasks of oral confrontation naming of objects, with only occasional semantic errors and omissions. The occurrence of naming difficulties in some patients with the SRO syndrome has been previously reported [32, 34]. His performance on tasks of phonemic discrimination and word–picture matching was quite accurate. Patient G.G. also performed relatively well on auditory and visual lexical decision tasks. Comprehension of aurally and visually presented sentences was relatively preserved. On tests of repetition, reading and writing-to-dictation of words and nonwords his performance was fairly accurate, with no evidence of grammatical-class effects.

Experimental investigation. Patient G.G. was given experimental tasks on nouns and verbs across two sessions (Table 2). In the first session (July 1991), on the Oral Confrontation Naming task [42] he showed a selective impairment in naming verbs, that was confirmed in the second session (March 1992). In both sessions, patient G.G. performed within normal limits in naming of nouns, while he showed a significantly greater difficulty in the production of verbs. On oral naming, various types of errors were observed on verbs (circumlocutions, verb nominalizations and semantic errors), while the few errors on nouns consisted of semantic ones and omissions. Occasional articulatory errors were ignored and are not reported in Table 2. In both sessions, patient G.G. was fairly accurate on the Auditory and Visual Lexical Decision tasks [43], on which no significant grammatical-class effect was observed. On the Word–Picture Matching task [42], in both sessions the patient performed flawlessly in the comprehension of nouns, but showed difficulty in the comprehension of verbs, making semantically-related errors. On this task, there was a nonsignificant tendency towards a greater impairment on verbs in the first session, while a significantly lower accuracy in the comprehension of verbs was observed in the second session.

Case 3

Patient G.P., a 67-year-old right-handed skilled worker, presented with a 3-year history of progressive language deterioration, due to a focal degenerative pathology [40, 64]. At the age of 64 years, he began to experience word-finding difficulty that gradually progressed over the ensuing years. His comprehension of spoken and written language also deteriorated

Table 2. Performance of patient G.G. across experimental tasks on nouns and verbs. The total number of stimuli (N) is reported for each task

	Nouns		Verbs			
	N	Errors (%)	N	Errors (%)	P	
First session						
Oral Confrontration Naming	48	6	48	31	0.002	$\chi^2 = 9.8$
Auditory Lexical Decision	10	0	10	0	n.s.	Fisher's test
Words ($N = 40$): Errors = 0%						
Nonwords ($N = 40$): Errors = 2%						
Visual Lexical Decision	10	0	10	10	n.s.	Fisher's test
Words ($N = 40$): Errors = 5%						
Nonwords ($N = 40$): Errors = 5%						
Word–Picture Matching	48	0	48	8	0.06	Fisher's test
(1 spoken word-3 pictures)						
Second session						
Oral Confrontation Naming	48	4	48	23	0.007	$\chi^2 = 7.2$
Auditory Lexical Decision	10	0	10	10	n.s.	Fisher's test
Words ($N = 40$): Errors = 2%						
Nonwords ($N = 40$): Errors = 0%						
Visual Lexical Decision	10	0	10	10	n.s.	Fisher's test
Words ($N = 40$): Errors = 5%						
Nonwords ($N = 40$): Errors = 10%						
Word–Picture Matching	48	0	48	17	0.005	$\chi^2 = 7.7$
(1 spoken word–3 pictures)						

progressively. His family did not observe changes in personality and intellect. Except for his communication difficulties, activities of daily living were otherwise unaffected. He remained able to perform housework and to drive his car. Elementary neurological examination was unremarkable. Routine laboratory investigations were normal.

Neuroimaging findings. MRI showed striking atrophy of the left temporal lobe, more evident in the anterior temporal regions (Fig. 1e). In addition, T2-weighted images revealed also some areas of increased signal intensity in the white matter of the left inferior frontal gyrus. A 99m Tc HM-PAO SPECT showed a marked perfusion abnormality in the left temporal regions (Fig. 1f).

Neuropsychological testing. On admission, patient G.P. was given several nonverbal cognitive tasks (Raven's Progressive Matrices [47], tests of visual memory, visual–visual semantic matching, tasks of oral, ideomotor and constructional apraxia) on which he performed normally. His performance on free recall verbal memory tasks was poor. By contrast, the patient was quite accurate on memory probe tasks with series of words.

His spontaneous speech was normally articulated, grammatical and fluent, but showed very severe word-finding difficulties, especially on nouns. Since admission, patient G.P. performed very poorly on tests of oral naming, independently of the modality of stimulus presentation (visual, tactile, from verbal description). On naming tasks, he made a great number of omissions, without showing any paraphasic error. Nonetheless, he was generally able to give appropriate definitions about most items he could not name or to demonstrate recognition of them through gestures. Phonemic discrimination was accurate, while G.P.'s ability to even recognize spoken and written words was severaly impaired, as suggested by his poor performance on both auditory and visual lexical decision tasks. On various word picture matching tasks, G.P. showed difficulty in accessing even general aspects of the meaning of a given word (e.g. *camel*), such as its superordinate category membership (in the

given example, a kind of *animal*). On some matching tasks, the patient was given one target-word and three pictures, corresponding to the target-word, a word semantically related to the target, and a word phonologically related to the target, respectively. Interestingly, on such tasks, he showed a remarkable tendency to point to pictures corresponding to words phonologically related to the target, in spite of his accurate phonemic discrimination [57]. Repetition of words and nonwords was largely intact. It is noteworthy that, on writing-to-dictation and reading, G.P. was severely impaired with irregular words (in Italian, on writing-to-dictation, words with ambiguous phoneme-to-grapheme mapping, on reading, words with lexically-assigned stress). By contrast, his performance on regular words and nonwords was considerably less affected. This pattern was consistent with a surface dysgraphia [53] and dyslexia [36]. No grammatical-class effect was found on tasks of reading and writing-to-dictation, probably because they could be performed by nonlexical procedures.

Experimental investigation. Patient G.P. was given experimental tasks on nouns and verbs across two sessions (Table 3). In a first session (July 1988), he was only given an Oral Confrontation Naming task [43], on which his overall performance was very poor, as expected in view of his striking naming difficulties. Nonetheless, a significantly greater impairment in producing nouns than verbs was detected. In a second session (December 1988), his ability to retrieve words had further deteriorated, due to the progressive course of aphasia [29, 52]. On this occasion, a shortened version of the Oral Confrontation Naming task was administered and only a statistical trend towards a greater impairment in naming nouns was observed, as a considerable decline in naming verbs had also occurred as time passed. On the other hand, his ability to name nouns had apparently deteriorated to a smaller extent between the two sessions, since a "floor effect" in naming nouns had been already documented in the first session. On the Oral Confrontation Naming task, in either sessions, most errors were circumlocutions and omissions. In the second session, he refused to perform a Written Confrontation Naming task [43]. Patient G.P. was also given Auditory and Visual Lexical Decision tasks [43]. On both tasks, he was significantly less accurate on nouns than on verbs. The performance reported in Table 3 was obtained by collapsing errors across two trials in either Lexical Decision task.*

In the Word–Picture Matching task [42], patient G.P. showed a significantly greater impairment in the comprehension of nouns than of verbs, making both semantically-related errors (12/48 on nouns, 4/48 on verbs) and non-related errors (14/48 on nouns, 2/48 on verbs). In this latter task, the patient also gave "don't know" responses on nouns (2/48) and, particularly, on verbs (13/48). Thus, all the different types of responses (correct, "don't know", errors) were taken into account in the statistical analysis reported in Table 3. Nonetheless, even if the "don't know" responses were randomly distributed among the three alternative choices (one target and two distractors), a significantly lower overall accuracy ($\chi^2 = 6.1$ $P = 0.01$) would be, in any case, observed on nouns (correct = 44%, errors = 56%) than on verbs (correct = 69%, errors = 31%).

DISCUSSION

In the present study differential lexical impairment of nouns and verbs was documented in patients with different sites of brain lesion. In summary, patient R.A. was at first selectively impaired on oral and written confrontation naming of verbs, while she performed quite accurately in production of nouns and on tasks of single word comprehension. Later in the progressive course of her aphasic syndrome, she developed mutism, with remarkable difficulties in tasks requiring speech production, and showed a disproportionate impairment

*The results obtained by patient G.P. on the Lexical Decision tasks were further analysed according to the Signal Detection Theory [28], in order to obtain separate indexes of sensitivity (d') and response bias (β). On both Lexical Decision tasks, the patient showed a diminished sensitivity to the signal (real words). In fact, the values of d' for patient G.P. (Auditory Lexical Decision: $d' = 1.68$; Visual Lexical Decision: $d' = 1.95$) were more than 9 S.D. below the mean of a group of 30 control subjects (Auditory Lexical Decision: $d' = 4.47 \pm 0.23$; Visual Lexical Decision: $d' = 4.42 \pm 0.27$), that is outside the 95% confidence interval for 99.73% of a population that is normally distributed. On the other hand, although the patient adopted a cautious criterion, the log transformed values of β for G.P. on both tasks (Auditory Lexical Decision: Log $\beta = 0.46$; Visual Lexical Decision: Log $\beta = 0.31$) were less than 1.96 S.D. above the mean of the control group (Auditory Lexical Decision: Log $\beta = -0.08 \pm 0.28$; Visual Lexical Decision: Log $\beta = -0.12 \pm 0.25$), that is within the 95% confidence interval for 95% of the population.

Table 3. Performance of patient G.P. across experimental tasks on nouns and verbs. The total number of stimuli (*N*) is reported for each task

	Nouns		Verbs			
	N	Errors (%)	*N*	Errors (%)	*P*	
First session						
Oral Confrontation Naming	30	93	36	64	0.004	$\chi^2 = 8.1$
Second session						
Oral Confrontation Naming	24	96	29	83	0.12	Fisher's test
Auditory Lexical Decision	20	65	20	25	0.01	$\chi^2 = 6.5$
Words ($N = 80$): Errors = 42%						
Nonwords ($N = 80$): Errors = 7%						
Visual Lexical Decision	20	50	20	20	0.04	$\chi^2 = 4.0$
Words ($N = 80$): Errors = 27%						
Nonwords ($N = 80$): Errors = 9%						
Word–Picture Matching	48	54	48	12	<0.001	$\chi^2 = 22.2$
(1 spoken word–3 pictures)						

in naming verbs. In addition, she became selectively impaired in the auditory comprehension of verbs. Neuropsychological, clinical and neuroimaging data from patient R.A. were consistent with a predominantly left posterior frontal lobe damage. As far as patient G.G. is concerned, he was at first selectively impaired on oral confrontation naming of verbs, showing quite accurate performance on naming nouns and on single word comprehension tasks. Later in the progressive course of illness, a selective impairment in the auditory comprehension of verbs was detected on a spoken word–picture matching task. Neuropsychological and neuroimaging data from patient G.G. were consistent with a left posterior frontal lobe damage. By contrast, the most remarkable finding in patient G.P. was the association between a striking atrophy of the left temporal lobe and a disproportionate impairment in processing nouns on tasks of oral confrontation naming, auditory and visual lexical decision, auditory comprehension.

In conclusion, although the neural correlates of lexical components are still to be clarified, converging sources of evidence from the current study suggest the following hypothesis: neural systems situated in the temporal lobe of the dominant hemisphere might be crucial to lexical mechanisms involved in the production and comprehension of nouns; on the other hand, neural systems situated in the posterior regions of the frontal lobe of the dominant hemisphere might play some critical role in lexical mechanisms involved in the production and comprehension of verbs. When we made this claim [17, 18], we did not mean to rule out the possibility that other brain regions may also be somewhow implicated in lexical processing of the categories noun and verb.

It is noteworthy that the two patients described here with a selective impairment of verbs (R.A. and G.G.), who sustained cortical damage relatively well circumscribed to the posterior regions of the left frontal lobe, were not agrammatics, that is their speech was not characterized by the omission of function words. Similarly, two other patients (H.W. and S.J.D.) with modality-specific impairments in oral and written production of verbs, respectively, who were not agrammatics, were reported by Caramazza and Hillis [5]. Altogether, these findings indicate that the mostly reported association between agrammatism and deficits in verb processing might reflect damage to distinct linguistic processes mediated by adjacent neural structures in the posterior regions of the frontal lobe of the dominant hemisphere.

It might be objected that patient G.P., with a disproportionate noun impairment, showed, although to a smaller extent, difficulties also in verb processing, particularly on oral naming. Indeed, the report of patients with category-specific deficits, who, nonetheless, may be remarkably impaired also on the less affected category is not uncommon. On the other hand, it could be hypothesized that the small lesions in the left inferior frontal gyrus revealed in patient G.P. by MRI scan could, perhaps, account for his difficulties in verb processing.

On the basis of our hypothesis, we have briefly reviewed the neuroanatomical correlates in so far reported patients with selective impairments of the categories noun and verb. In a coarse-grain analysis, we have only taken into account the localizing information derived from single-case studies of patients with grammatical-class impairments. The neuroimaging data reported in such single-case studies are in fact not substantially dissimilar to the findings obtained in group studies on anomic and agrammatic patients [41, 68].

So far, at least eight patients with impairments of the category noun (including our patient G.P.) have been investigated in single-case studies [15, 17, 18, 42, 44, 67]. It is noteworthy that all of them had lesions essentially involving the left temporal lobe (Table 4). On the other hand, up till now, at least 11 patients with impairments of the category verb (including our patients R.A. and G.G.) have been reported in single-case studies [2, 5, 15, 17, 18, 37, 42]. On the whole, it appears that the neuroanatomical correlates of verb impairments available from these investigations are definitely less univocal (Table 5). Seven out of 11 patients with verb impairments had in fact lesions involving the frontal lobe, while no fewer than six out of 11 subjects had lesions involving the temporal lobe. As noted previously, Table 5 clearly shows that, until recently [15, 17, 18], selective impairments of verbs had been reported mostly in patients with quite extensive lesions, involving two to three cerebral lobes.

We have briefly reviewed some clinical and neuroimaging data in the four patients with verb impairments whose computerized tomography (CT) scans were not reported to reveal frontal lesions. The agrammatic patient R.O.X., investigated by McCarthy and Warrington [37], was impaired both in the retrieval and in the comprehension of verbs. In this patient, a progressive degenerative disease was suspected and CT showed cortical atrophy. Interestingly, R.O.X. presented some clinical manifestations that would seem fairly consistent with frontal lobe damage (lack of spontaneity of speech, palilalia, impaired and perseverative performance on verbal fluency tasks, personality changes, with social withdrawal and aggressive outbursts). Patient G.O.S., who was described by Baxter and Warrington [2], showed spelling difficulties with verbs. She had sustained a large intracerebral hematoma with surrounding oedema in the left temporo-parietal region. We were kindly given the opportunity to examine the original CT scans of patient G.O.S. (Warrington, personal communication). On the basis of such scans, it would seem to us that the lesion did also extend beyond the sylvian fissure, thus partially involving the posterior regions of the left frontal lobe. Patient F.D.P., who was reported by Miceli and co-workers [31], showed a selective impairment in the production and comprehension of verbs and presented with agrammatic speech. CT scan revealed a haemorrhagic temporo-parietal lesion. Patient H.W., who was investigated by Caramazza and Hillis [4, 5], was impaired in oral production of verbs. She was reported to have previous strokes, with several ischemic areas in the parietal and occipital lobes, which were thought to be secondary to cardiac embolism. Her spontaneous speech was grammatical, with occasional articulatory errors. H.W. also showed mild oral–verbal apraxia. The neuroimaging data from these latter patients with selective impairments of verbs and without direct evidence for frontal lesions could somehow challenge the hypothesis of a critical role of the frontal lobe in verb

Table 4. Neuroimaging data from single-case studies of patients with impairments of the category noun. F = frontal, T = temporal, P = parietal, O = occipital

Authors	Case	Lesion site	Neuroimaging	Impaired experimental task(s)
Miceli *et al.*, 1988	A.A.	Right T, left T	CT	Oral Confrontation Naming Spoken Word–Picture Matching
	S.F.	Left T	CT	Oral Confrontation Naming
	A.E.	Right F, left T	CT	Oral Confrontation Naming
Zingeser and Berndt, 1988	H.Y.	Left TPO	MRI	Oral Confrontation Naming Written Confrontation Naming
Daniele *et al.*, 1992, 1993	G.P.	Left T	MRI, SPECT	Oral Confrontation Naming Auditory Lexical Decision Visual Lexical Decision Spoken Word–Picture Matching
Damasio and Tranel, 1993	AN-1033	Left T	MRI	Oral Confrontation Naming Written Confrontation Naming
	Boswell	Left T	MRI	Oral Confrontation Naming Written Confrontation Naming
Miozzo *et al.*, in preparation	A.L.	Left T	MRI	Oral Confrontation Naming Written Confrontation Naming

Table 5. Neuroimaging data from single-case studies of patients with impairments of the category verb. F = frontal, T = temporal, P = parietal, O = occipital

Authors	Case	Lesion site	Neuroimaging	Impaired experimental task(s)
Baxter and Warrington, 1985	G.O.S.	Left **TP**	CT	Writing-to-dictation
McCarthy and Warrington, 1985	R.O.X.	Cortical atrophy	CT	Oral Confrontation Naming Spoken Word–Picture Matching
Miceli *et al.*, 1988	F.D.P.	Left TP	CT	Oral Confrontation Naming Spoken Word–Picture Matching
	C.S.	Right FT	CT	Oral Confrontation Naming Spoken Word–Picture Matching
	F.S.	Left FT	CT	Oral Confrontation Naming
	A.M.	Left **FTP**	CT	Oral Confrontation Naming
Caramazza and Hillis, 1991	H.W.	Left PO	CT	Oral Confrontation Naming Reading
	S.J.D.	Left FT	CT	Written Confrontation Naming Writing-to-dictation
Daniele *et al.*, 1992, 1993	R.A.	Left F	MRI, SPECT	Oral Confrontation Naming Written Confrontation Naming Spoken Word–Picture Matching
	G.G.	Left F	MRI, SPECT	Oral Confrontation Naming Spoken Word–Picture Matching
Damasio and Tranel, 1993	KJ-1360	Left F	MRI	Oral Confrontation Naming Written Confrontation Naming

processing. However, it should be considered that the localizing information in these subjects could have been only derived on the basis of CT scan data. Thus, the possibility actually exists that small lesions in critical frontal areas could have escaped detection. Perhaps, this eventuality could be indirectly suggested by the occurrence in the above-mentioned patients of syndromes, such as agrammatism or oral-verbal apraxia, that are usually associated with lesions in the posterior left frontal lobe.

Furthermore, the results of some PET studies on groups of normal individuals do also appear fairly consistent with the hypothesis of some critical role for the left posterior frontal regions in verb production. Petersen and co-workers [45] observed that the vocalization of an appropriate verb for an aurally or visually presented noun (for example, if "cake" is presented, say "eat") resulted in activation of the left inferior frontal lobe. Quite similarly, Wise and co-workers [65] found that silent verb generation (thinking, without vocalization, of a list of verbs appropriate to an aurally presented noun) activated the supplementary motor area and the posterior parts of the left medius and inferior frontal gyri (including Broca's area). It is interesting to note that these latter gyri resulted in being particularly affected on MRI scan in our patient R.A., who was impaired in naming and comprehension of verbs.

According to Caramazza and coworkers [7], the observation of modality-specific grammatical-class impairments [5] support the hypothesis that orthographic and phonological information about each of these word classes (nouns and verbs) is represented in distinct neural structures. Moreover, similarly to our proposal, Caramazza suggests that the verb–noun distinctions appear to be distributed along the anterior/posterior axis of the language area [6]. As mentioned before, one possible interpretation proposed by Damasio and Tranel is that there are systems that mediate between concepts and nouns located in the left temporal cortices, while equivalent mediation systems between concepts and verbs might be located in left frontal cortices [15].

From a theoretical point of view, the use of single patients in order to put forward general hypotheses about possible correlations between neural structures and cognitive functions might be questioned. It must be pointed out, however, that the investigation of single cases is generally considered crucial to the identification of damaged functional components, that, in turn, is a necessary presupposition of any hypothesis of correlation between a given functional component and neural systems critical for that component. Nevertheless, such hypotheses must be corroborated by further studies documenting other cases with identical functional lesions [3].

Various investigations support the view that lesions relatively well circumscribed to the left temporal lobe may give rise to selective impairments of various lexical and semantic categories, such as nouns, animals and other living things [15, 31, 38, 39, 42, 49, 63]. On the other hand, the critical role in verb processing suggested by the current study for the frontal lobe might invite speculation. Warrington and McCarthy [62] proposed that the relative salience of various types of information from different sensory and motor channels in the acquisition of knowledge about a concept could be the basis of the categorical organization of semantic knowledge. According to this account, Warrington and McCarthy [62] also suggested that the information derived from motor channels is likely to be highly salient for the comprehension of action verbs.

In principle, it would seem to us not implausible to speculate that, since the frontal lobe *is* involved in programming and executing voluntary movement, during philogeny this lobe could have acquired some critical role also for both semantic representations of actions [22] and lexical components involved in processing of action names, i.e. verbs.

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