PERGAMON

Neuropsychologia 41 (2003) 1189–1198

NEUROPSYCHOLOGIA

www.elsevier.com/locate/neuropsychologia

Grammatical processing of nouns and verbs in left frontal cortex?

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Received 23 January 2002; received in revised form 7 January 2003; accepted 9 January 2003

Abstract

We report the case of a brain-damaged subject R.C. who is more impaired at producing grammatical forms of words and pseudo-words used as verbs (*he judges*, *he wugs*) than of the same words used as nouns (*the judges*, *the wugs*). This pattern of performance constitutes the first clear demonstration that grammatical knowledge about verbs can be selectively impaired following brain damage. A comparison of R.C.'s behavioral and neurological profile with that of a patient who shows similar difficulties with nouns suggests that nouns and verbs are processed by separate neural systems with components in the left frontal lobe.

Keywords: Agrammatism; Grammatical categories; Morphosyntax

1. Introduction

Damage to the left frontal cortex often results in a distinctive syndrome of impaired language production known as agrammatic aphasia, so called because one of its most conspicuous features is the omission and misuse of grammatical elements in speech. Patients with this disorder tend to have particular difficulty generating inflectional morphemes—that is, affixes like *-s* in *songs* and *-ed* in *walked*—which convey syntactic information about the words they modify and about the relations between words within a sentence [20,39].

Why the ability to produce inflectional morphemes should depend on intact left frontal structures is not well understood. Some researchers have argued that the apparent morphological deficit in agrammatism stems from a more general loss of knowledge about grammatical rules [3,26] while others have suggested that it reflects a tendency to minimize the number of sounds that must be produced by patients who have difficulties with the motor output of speech [25,29]. Yet, patients with left frontal damage do not always exhibit uniform problems with inflection. Certain inflectional endings (like *-s* in *songs*) may be preserved, while others (like *-ed* in *walked*) may be lost, in a manner that varies from case to case [34]. This fact is not easily reconciled with either of the above accounts.

One possibility that has not previously been considered is that the left frontal cortex contains a number of related but functionally discrete neural systems engaged in morphological processing. This hypothesis is motivated by the observation that grammatical categories of words—nouns, verbs, adjectives, and so forth—are defined in part by the kinds of morphological transformations they can undergo. Thus, in English, only verbs can occur with past-tense morphology (as in *walked*), while only nouns can be marked for plural number (as in *songs*). These category specific operations might be subserved by dedicated neural processors for nominal and verbal morphology. Alternatively, a single morphological system might receive separate streams of input corresponding to words of different grammatical categories. In either case, we would expect that noun and verb processing should sometimes dissociate following brain damage.

Indeed, there is ample evidence that language production in aphasia may break down along lines of grammatical category. Some patients are poor at naming verbs relative to nouns [4,6,9,33,35], while others are worse at naming nouns than verbs [2,35,47,56]. But these deficits have most often been interpreted as resulting from damage to sensorimotor networks that store or mediate access to conceptual knowledge about objects and actions [12,43,54]. By contrast, relatively little discussion has focused on the possibility that they reflect the loss of neural representations of nouns and verbs as morphological types [9,50,51], and no attempt has been made to characterize such putative representations at the level of cortical function, in spite of the crucial role that grammatical category information plays in language processing.

Even if it is true that some apparently category specific impairments arise as a byproduct of degraded conceptual

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doi:10.1016/S0028-3932(03)00037-X

knowledge about action or object words, it may be that other cases offer evidence of damage to dedicated grammatical processors. For example, only the latter kind of impairment would be expected to manifest in morphological processing tasks. A clear interaction of this sort has been described just once in the neuropsychological literature—one brain-damaged subject, J.R., made more errors in producing inflected forms of nouns than verbs [51]. However, in the absence of a double dissociation, it is unclear whether noun morphology may simply be more difficult to produce in the context of brain damage.

Here, we present the case of an agrammatic aphasic subject, R.C., who has more severe difficulties producing the inflected forms of verbs than nouns. This impairment extends to both morphologically regular verbs (like *walked*) and irregular verbs (like *ran*), contrary to the prediction that anterior brain damage should lead to greater difficulty with regular forms [55], and also to pseudo-words (like *wug*) that have no stored representation. R.C.'s pattern of production, compared with that of subject J.R., supports the hypothesis that the production of noun and verb morphology may be spared or impaired differentially following brain damage. This in turn implies that these two cognitive mechanisms have separate neural substrates. Analysis of the neurological lesions in J.R. and R.C. suggests that both mechanisms depend on structures in the left frontal lobe.

2. Methods

2.1. Neurological profile

R.C. is a right-handed, 65-year-old male with high school and vocational education. Formerly manager of a school bus transportation company, he became aphasic in 1994 following an ischemic stroke. An MR scan in 1997 revealed damage to the left posterior frontal lobe, including Broca's area and anterior portions of prefrontal cortex, as well as underlying parts of the insula, putamen, pallidus and internal capsule. There is also some involvement of the parietal operculum and the superior-anterior portion of the temporal lobe, as well as clear enlargement of the left lateral ventricle (Fig. 1).

2.2. Neuropsychological profile

At the time of testing (5–6 years post-trauma), R.C. presented with non-fluent speech and marked articulatory difficulties. Both are hallmarks of the clinical syndrome of

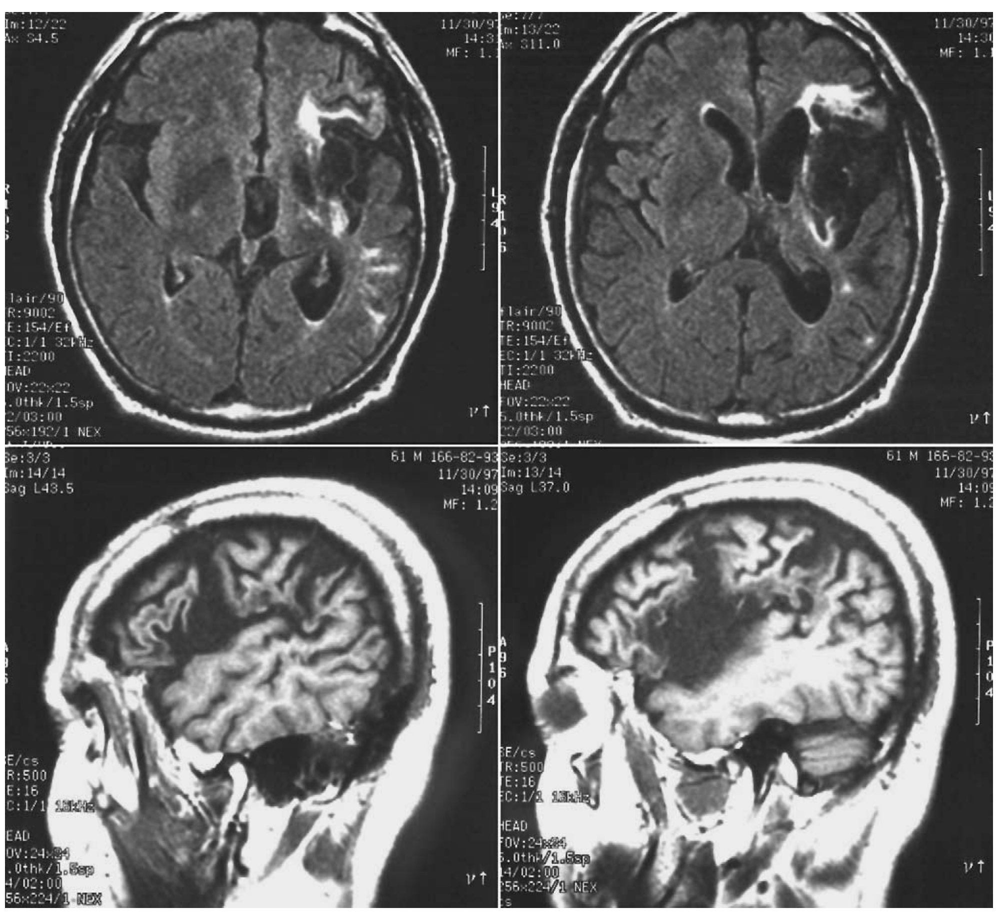

Fig. 1. Representative axial FLAIR (above) and sagittal T1-weighted (below) MRI sections showing brain damage in R.C., who presents with a lesion primarily affecting the left posterior frontal lobe and underlying structures.

Broca's aphasia, consistent with the anterior disposition of his lesion [21]. R.C.'s spontaneous utterances were short and telegraphic, and frequently lacked overt syntactic structure. For instance, he defined the word *pan* as follows: "Lots of things. Cooking. Eggs. Bacon." On a category fluency task R.C. produced eight unique names of animals in 1 min. His digit span was four digits forward and three backward.

2.2.1. Naming

R.C. was relatively unimpaired at naming objects. He scored 169/175 correct on the Philadelphia Naming Test [46] and was not sensitive to target frequency (he named 30/31 high-frequency and 96/101 low-frequency items). However, he correctly produced only 18/23 three- and four-syllable names, versus 151/152 one- and two-syllable names ($\chi^2(1) = 38.1$, $P < 0.001$).

To assess whether R.C.'s naming ability is affected by the semantic category of the target item, we asked him to name the 260 Snodgrass–Vanderwart pictures [53] on two separate occasions. We also presented a battery of 142 line drawings designed to test for semantic category effects [24]. Overall R.C. named 522/662 of these items correctly. The only categories for which his performance was significantly worse than his mean naming performance were furniture (26/45; $\chi^2(1) = 11.98$, $P < 0.01$) and musical instruments (10/18; $\chi^2(1) = 2.42$, $P < 0.02$).

2.2.2. Repetition and lexical decision

R.C. correctly repeated 167/175 of the names of items on the Philadelphia Naming Test; 6/8 of his errors occurred with low-frequency items. On a separate test designed to probe for concreteness effects, R.C. correctly repeated 16/20 abstract words and 18/20 concrete words. R.C. was more impaired at repeating non-words (41/90), but was better with one-syllable non-words (19/30) than with two- and three-syllable items (22/60; $\chi^2(1) = 5.71$, $P < 0.01$).

We also presented a list of 60 real words and 60 non-words matched for length, and asked R.C. first to decide whether the stimulus word was real or not, and then to repeat it. His lexical decision response was correct on 102/120 trials (16/18 errors were false positives). R.C. correctly repeated 46/60 real words but only 14/60 non-words ($\chi^2(1) = 34.1$, $P < 0.001$). A total of 16/46 of his errors in non-word repetition involved lexicalization (e.g. *yake* → "lake"), while 5/14 of his errors with real words were substitutions (*skate* → "state"). In all other cases, R.C. produced a non-word response (*trunskit* → [tɹɛntʃɪk], *stumble* → [skʌmbl]).

2.2.3. Auditory processing

R.C. showed fair performance (151/160) on a test of auditory discrimination and scored 109/111 on a spoken word to written word matching task.

2.2.4. Comprehension

R.C. was mildly impaired (108/125) in an auditory word to picture matching task in which he was asked to decide whether the stimulus word was the name of a simultaneously presented picture. Of his errors, 12/17 were false positive responses to a semantically related foil.

We also administered two synonym triplets tasks [5], one of which varied the grammatical category of the items (nouns and verbs) by trial, while the other varied concreteness. On each trial, R.C. was presented with three words and required to identify the one word that did not belong with the other two (e.g. *lake* in the triplet *lake–brook–stream*). He responded correctly to 11/16 noun triplets and 14/16 verb triplets, and to 18/26 abstract and 19/26 concrete triplets.

2.3. Experimental tasks

2.3.1. Object/action picture naming

Ninety-eight pictures of actions and objects were matched across category for visual complexity and for the length (in syllables and phonemes), familiarity, and frequency of their target names [17]. Ratings for familiarity and visual complexity were based on the mean values (on scales of 1–5) assigned by 56 undergraduates.

2.3.2. Noun/verb repetition

R.C. was asked to repeat a total of 1377 adjectives, nouns and verbs (Table 1). A subset of this corpus included 360 words that were matched across category for frequency and length in syllables. On this subset, in addition to effects of grammatical category, we found that R.C. correctly repeated more high-frequency words (147/180) than low-frequency words (127/180; $\chi^2(1) = 6.10$, $P < 0.01$). His performance did not differ for one-syllable (104/120) and two-syllable (100/120) words, but declined for three- and four-syllable words (69/120; $\chi^2(1) = 33.1$, $P < 0.001$).

2.3.3. Sentence completion: noun/verb contrasts

To investigate R.C.'s ability to use inflectional morphology, we used a simple test in which he was required to complete auditorily presented sentence frames using the appropriate spoken forms of noun and verb homonyms. For example, given the sentence frame "These people judge, this person . . . ", R.C. was required to produce the verb *judges*. The same word, used as a noun, was required to complete the frame "This is a judge, these are . . . ". Using homonyms in this test has the obvious advantage of controlling for possible formal differences between nouns and verbs [9,27].

Three different sets of stimulus items were used with the sentence frames just described. The first set consisted of 48

Table 1
Repetition by category

	Unmatched		Matched	
	n	%	*n*	%
Adjectives	233	74.7	120	83.3
Nouns	837	84.8	120	77.5
Verbs	307	58.6	120	66.7

Table 2
R.C.'s performance with subsets of the items used in all sentence completion conditions (number of N(oun) and V(erb) items in parentheses), compared to the performance of four control subjects of similar age and educational level

Subject	Age	Education	Homonyms (simple)		Homonyms (complex)		Pseudo-words		Regular words		Irregular words	
			N (28)	V (28)	N (26)	V (26)	N (24)	V (24)	N (34)	V (44)	N (58)	V (66)
R.C.	65	14	21	10	20	2	12	5	28	19	48	15
Average	*67.8*	*14.0*	*25.8*	*26.5*	*25.8*	*24.3*	*19.3*	*20.0*	*32.3*	*41.0*	*54.5*	*58.3*
S.E.	*1.95*	*0*	*1.18*	*1.06*	*0.22*	*0.67*	*1.61*	*1.67*	*1.57*	*1.41*	*0.58*	*2.72*
1	70	14	22	23	25	22	14	15	27	37	53	56
2	67	14	27	27	26	25	20	20	34	43	56	65
3	72	14	28	28	26	25	22	24	34	44	54	51
4	62	14	26	28	26	25	21	21	34	40	55	61

The average and standard error (S.E.) for all control subjects is in italic. Pairwise *t*-contrasts revealed no difference between nouns and verbs for the control group on any task.

one-syllable and 8 two-syllable words taking the inflectional affix [s] or [z] (e.g. *grill* [gɹɪl], *grills* [gɹɪlz]); the second set consisted of 47 one-syllable and 7 two-syllable words taking the inflection [ɪz] (e.g. *judge* [dʒʌdʒ], *judges* [dʒʌdʒɪz]). Following Goodglass and Berko [20], we refer to the former items as taking "simple" affixes and the latter items as taking "complex" affixes, where the term "complex" denotes that [ɪz] applies to fewer cases and results in a change in the syllable structure of the inflected word.[1] The third set of stimuli included 48 one-syllable pseudo-words, formally plausible but meaningless syllables like *wug*, *torge* and *flonk*. We used four different kinds of sentence frame, all along the lines of those given above, such that R.C. was supposed to produce each stimulus item (on different trials) as a singular noun, a plural noun, a third person singular verb, and a third person plural verb.

For words requiring simple affixes, the mean lemma frequency (f_λ) [17] was 57.7 for nouns and 60.3 for verbs ($t(55) = -0.13$, N.S., paired). Nouns taking complex affixes were more frequent ($f_\lambda = 83.5$) than their verb homophones (33.9; $t(54) = 2.98$, $P < 0.005$, paired), a difference that may explain in part why R.C.'s apparent disadvantage for verbs was more severe in this condition than in the simple affix condition. However, we note that patient J.R. presented with the opposite interaction (the magnitude of his disadvantage for nouns increased in the complex affix condition) using the same stimuli [51], indicating that phonological complexity may contribute to impairments in performance when a selective deficit for one grammatical category is present. We also note that R.C.'s production performance is affected by length (in syllables) of the target in a variety of tasks; this length effect might interact with any grammatical category effect that is present.

2.3.4. Sentence completion: regular/irregular contrasts

Past-tense and unmarked forms of verbs were elicited using frames of the following types: "Yesterday I walked, and tomorrow I will also . . . "; "Tomorrow I will walk; yesterday I also . . . ". Two lists of verbs were used. List 1 consisted of 133 verbs ($0 < f_\lambda = 300$), including 77 verbs with irregular past-tense forms (mean surface frequency of past and unmarked forms $f_s = 24.7$) and 56 verbs with regular past-tense forms ($f_s = 21.3$; $t(264) = 1.04$, N.S.). List 2 consisted of 26 "high-frequency" verbs ($300 < f_\lambda < 650$), including 13 with irregular past-tense forms ($f_s = 146.4$) and 13 with regular past-tense forms ($f_s = 123.4$, $t(50) = 1.26$, N.S.).

We also elicited regular and irregular plural forms of nouns using the sentence frames described above (Section 2.3.3) with a list of 46 nouns ($0 < f_\lambda \leq 300$), including 17 with irregular plurals ($f_s = 19.4$) and 29 with regular plurals ($f_s = 29.1$; $t(90) = -0.922$, N.S.). There was no difference in mean surface frequency between regular nouns and verbs from list 1 ($t(168) = 1.23$, N.S.) or between irregular nouns and verbs from the same list ($t(186) = -0.966$, N.S.).

2.4. Control subjects

Four control subjects with no history of neurological disorder, matched to R.C. for age and educational level (see Table 2), completed each of the repetition tasks described in Sections 2.3.3 and 2.3.4 using subsets of the stimuli presented to R.C. Their performance is detailed in Table 2.

2.5. Use of human subjects

All experiments described in this paper were part of a study approved by the Standing Committee on the Use of Human Subjects in Research at Harvard University, and were performed in compliance with the committee's guidelines.

3. Results

3.1. Noun and verb production

Like many anterior aphasic patients [34], R.C. has more difficulty producing verbs than nouns in speech. For

[1] In other words, the affix [ɪz] is *phonologically* more complex than [z]; morphologically they are of equivalent complexity.

example, he correctly named 45/49 noun pictures but only 29/49 verb pictures ($\chi^2(1) = 14.13$, $P < 0.001$). This apparent disadvantage for verbs persisted on repetition tests using both concrete and abstract nouns, verbs, and adjectives (Table 1), suggesting that R.C.'s impairment is not limited to pictureable actions. When nouns, verbs, and adjectives were matched to control possible effects of length and frequency, he was significantly worse with verbs than with either nouns ($\chi^2(1) = 3.50$, $P < 0.05$) or adjectives ($\chi^2(1) = 8.88$, $P < 0.005$). The observation that R.C. was equally good at repeating nouns and adjectives ($\chi^2(1) = 1.28$, N.S.) implies that his pattern of performance can appropriately be described as reflecting a deficit in verb production rather than, for example, the selective sparing of nouns. Moreover, we found no indication that R.C.'s production performance is sensitive to the concreteness of target words.

3.2. Morphological processing of nouns and verbs

Overall, R.C. produced the correct form more than twice as often for nouns (160/220) as for verbs (65/220; $\chi^2(1) = 82.08$, $P < 0.001$). We also analyzed separately R.C.'s performance with words (like *sails*) that take the phonologically simple affix [z] and [s] and those (like *judges*) that take the complex affix [ɪz]. The results indicate that R.C. is worse with verbs than with nouns in both conditions, though this dissociation is more striking when phonologically complex endings are required. R.C. correctly generated 71/112 noun forms and 49/112 verb forms for words requiring simple affixes ($\chi^2(1) = 8.70$, $P < 0.005$); for words taking complex affixes, he produced 89/108 correct noun forms and only 16/108 correct verb forms ($\chi^2(1) = 98.80$, $P < 0.001$; however, see Section 2.3.3 for a discussion of effects of frequency in the complex affix condition). An analysis of R.C.'s errors on this task is given in Table 3.

The finding that R.C. has more difficulty completing sentences like *these people guide* than sentences like *this is a guide* suggests that he is impaired at retrieving and manipulating grammatical knowledge about verbs. At the same time, the results leave open the possibility that R.C.'s core deficit in word production is delimited by differences in meaning (i.e. semantic differences) between nouns and verbs, rather than differences in grammatical function. We therefore asked R.C. to perform the same task with pseudo-words. Within the appropriate sentence contexts, pseudo-words behave grammatically like nouns and verbs (e.g. *these are wugs*; *this person wugs*). However, they have no stored semantic representations, and therefore any impairment in producing pseudo-words cannot be traced to damaged knowledge of meaning.

The pattern of results obtained with pseudo-words was nearly identical to the pattern with real words: R.C. produced the correct forms for nouns (48/96) more often than verbs (27/96; $\chi^2(1) = 9.61$, $P < 0.001$), despite the fact that the *same* pseudo-words were used as nouns and verbs. There were not enough pseudo-words requiring the [ɪz] affix to permit an analysis of the effect of phonological complexity on this task.

Table 3
R.C.'s errors in sentence completion with noun and verb homonyms

	Homonyms (simple)		Homonyms (complex)	
	Nouns (112)	Verbs (112)	Nouns (108)	Verbs (108)
Correct	71	49	89	16
Errors	41	63	19	92
Perseveration	30	46	12	39
Formal	6	4	2	1
Phonological	4	1	2	0
Morphological	n/a	7	n/a	49
Mixed	1	5	2	4

The number of items in each category is given in parentheses. *Perseveration* errors include repetitions of cued forms, with a failure to modify tense-marking (e.g. saying "boards" instead of *board*); *formal* errors are cases in which R.C. produced a word that was phonologically similar to the target ("needles" for *needs*); and *phonological* errors are cases in which R.C. made phonological or articulatory errors resulting in a non-word response ([kʷikʷɛst] for *request*). Errors were coded as *morphological* when R.C. produced an inflectional form other than the one required ("danced" for *dance*); this error type was only possible for verbs. The *mixed* category includes other kinds of errors and exemplars of more than one error type ("toast" for *coaches*).

3.3. Regular and irregular morphology

Having established that R.C. exhibits a morphological impairment affecting verbs more severely than nouns, we now report on his ability to produce morphologically regular and irregular nouns and verbs. Words that are regular with respect to a given morphological alternation (e.g. between past and present tense verb forms) undergo transformations that are predictable and rule-based (like the affixation of *-ed* to form *walked*) and that can be applied productively to novel words (*wugged*). By contrast, irregular words have unpredictable alternants that must be retrieved from memory (*ran*, *dug*, *sang*).

We found that R.C. was far better at producing regular verbs than irregular verbs. With words from list 1, R.C. produced correct regular forms (48/112) much more often than correct irregular forms (27/154; $\chi^2(1) = 20.54$, $P < 0.001$). The post hoc tests revealed no difference in surface frequency between correctly and incorrectly produced regular verbs ($t(108) = -0.524$, N.S.) or irregular verbs ($t(152) = -0.018$, N.S.) for words with $f_\lambda \leq 300$.

The same pattern of results with respect to regularity was obtained for "high-frequency" (list 2) verbs. R.C. correctly produced 12/26 regular verbs but only 2/26 irregular verbs ($\chi^2(1) = 9.77$, $P < 0.005$). However, we did observe a strong reverse frequency effect with items from this list: regular and irregular verbs that R.C. produced correctly had lower mean surface frequency ratings than incorrectly produced verbs ($t(50) = 3.64$, $P < 0.001$). No such effect was found in any other production task.

Table 4
R.C.'s errors in production of verbs with regular and irregular past-tense forms

	Regular (138)	Irregular (182)
Correct	60	29
Errors	78	153
Perseveration	67	99
Overregularization	n/a	16
Participle	1	13
Formal	2	5
Mixed	8	20

The number of items in each category is given in parentheses. *Perseveration* errors include repetitions of cued forms, with a failure to modify tense-marking (e.g. saying "draw" instead of *drew*); *overregularization* errors involve incorrect application of regular past-tense morphology ("teached"); *participle* errors are cases in which R.C. produced a participial form rather than a past-tense or unmarked form ("bitten"); *formal* errors are cases in which R.C. produced a word that was phonologically similar to the target ("sing" for *sting*). The *mixed* category includes other kinds of errors and exemplars of more than one error type ("clunged").

Of R.C.'s errors with irregular verbs from both lists, only 16/153 involved the extraneous production of regular endings ("teached", "sayed"). Perseverations of the cue form (e.g. producing "helped" in response to the frame "Yesterday I helped, tomorrow I will also ...") accounted for a large majority of errors with both regular (67/78) and irregular verbs (99/153). A listing of other error types and their prevalence is given in Table 4.

R.C. showed no significant difference in the production of nouns with irregular plural forms (like *mice* and *wolves*) and those with regular plurals (like *clocks*). He correctly produced 48/58 regular and 28/34 irregular nouns ($\chi^2(1) < 0.01$, N.S.), and in only three instances did he apply regular inflections inappropriately ("shelfs", "halfs", "elfs"). Most of the rest of his interpretable errors with both regular and irregular nouns (8/16) were perseverations.

To control for possible effects of length and regularity of target responses, we performed a sequential logistic regression, entering the following variables (in the order listed) as predictors of correct production: length in phonemes of the target, log surface frequency of the target, the interaction between regularity and grammatical category, grammatical category, and regularity (Nagelkerke $R^2 = 0.345$, omnibus $\chi^2(5) = 121.3$, $P < 0.001$). Neither length (Wald $\chi^2(1) = 0.017$, N.S.) nor frequency (Wald $\chi^2(1) = 0.213$, N.S.) emerged as a significant predictor. Likewise, regularity had no effect when grammatical category and the interaction term were controlled (Wald $\chi^2(1) = 1.25$, N.S.). However, the effect of grammatical category was highly significant (Wald $\chi^2(1) = 18.01$, $P < 0.001$), as was the interaction between grammatical category and regularity (Wald $\chi^2(1) = 4.64$, $P < 0.05$), confirming that R.C. is worse with verbs than nouns overall and that regularity affects his production of verbs, but not of nouns.

4. Discussion

R.C. is an agrammatic aphasic subject who had more difficulty naming and repeating verbs than nouns, and made more errors producing categorically ambiguous words and pseudo-words when context indicated that they were verbs than when they were nouns. R.C. also made some errors with nouns, and especially with pseudo-words used as nouns, suggesting that his morphological deficit is not limited to verb processing. Nevertheless, it is clear that with respect to inflectional morphology, verbs are disproportionately impaired. To our knowledge, this is the first case in which such a pattern has been documented unambiguously.

We have posited that R.C.'s deficit in producing verbs relative to nouns results from damage to neural regions involved in representing information about this category of words. A more trivial explanation is that verbs are simply more difficult to produce than nouns, and that this is reflected in the poor performance of R.C. (and patients like him) in tasks that probe knowledge of verbs. This cannot be the case, however. A patient we reported earlier, J.R., presented with the opposite pattern: he was better at producing real words and pseudo-words when they were used as verbs than when they were used as nouns in the sentence completion test (Table 5), and had greater difficulties naming and repeating nouns than verbs. Like R.C., J.R. showed no effects of concreteness or imageability that could account for his noun production deficit and no analogous deficit in comprehension. The double dissociation between R.C. and J.R. in performance with real words and pseudo-words implies that their impairments result from damage to representations of knowledge about verbs and nouns, respectively.

Furthermore, the kinds of representations that are damaged in these cases seem to be grammatical, and not directly involved in retrieving stored information about word form or meaning; otherwise it is not clear how we might account for the observed deficits with pseudo-words, which presumably have no memorized features. This interpretation differs radically from neuropsychological models that do not postulate distinct representations for grammatical (as opposed to conceptual) categories, as we will discuss below. We

Table 5
Sentence completion with noun–verb homonyms and pseudo-words

	R.C.		J.R.	
	n	%	*n*	%
Real words				
Nouns	220	72.7	550	81.0
Verbs	220	29.5	550	93.0
Pseudo-words				
Nouns	96	50.0	96	54.1
Verbs	96	28.1	96	81.3

assume that information about the grammatical category of a word is retrieved at some stage subsequent to the retrieval of its meaning, and that this information is critical in specifying its syntactic properties—for instance, tense, person, and number [11,28,30]. Such properties may be overtly marked by the addition of inflectional morphemes.

There are at least two ways in which grammatical category could play a role in the processing of inflectional morphology. One possibility is that the morphological system consists of separate processing components for nouns, verbs, and other kinds of words. The second is that separate circuits retrieve information relating to a word's grammatical category and then feed into a unitary system for processing morphology. Though our results do not distinguish between these alternatives, they do suggest that future research should be directed along these lines.

4.1. Verb production and inflectional morphology

As we mentioned in the Introduction, several studies in the neuropsychological literature have described patients who have greater difficulty producing verbs than nouns [4,6,9,32,35]. However, at least some of these putative verb impairments seem to be of a very different type than the deficit exhibited by R.C. For example, it has long been observed that some patients who perform poorly in action naming tasks will occasionally produce novel verbs using noun stems, like the neologism "laddering" in place of *climbing* [32,44]. What is notable about such errors is that they seem to imply that patients who produce them have intact knowledge of verbal morphology: that is, these patients correctly produce the progressive inflection [iŋ] even though they are unable to retrieve the correct verb stems from the lexicon. We suggest that in these cases, apparent grammatical category effects do not result from dysfunctional morphological processing mechanisms. Some such deficits may stem from damage to systems that are not truly grammatical in nature, such as conceptual networks that store information about objects and actions [32]. In other cases, the effect seems not to be a result of damage to conceptual representations, but to the access of specific lexical forms that are grammatically specified [44].

On the other hand, as we have stressed repeatedly, it appears that at least some dissociations in the production of nouns and verbs are attributable to the loss of grammatical knowledge about one of these categories. Although we have argued that failures in tasks that involve morphosyntactic manipulation are important in establishing the presence of such grammatical deficits, it does not follow that grammatical dissociations will only be observed in tasks that explicitly involve morphosyntactic processing. Indeed, both J.R. and R.C. displayed impairments in ostensibly nominal tasks like repetition and picture naming. This suggests that morphosyntactic processing (or at any rate the retrieval of a word's morphosyntactic category) is a mandatory step in lexical production, regardless of whether the word that is produced bears overt inflectional morphology.[2]

4.2. Neuroanatomical correlates of grammatical processing

From a neuroanatomical point of view it is noteworthy that both R.C. and J.R. have damage to the left inferior frontal cortex (including Broca's area) and underlying parts of the insular cortex (Figs. 1 and 2). Numerous neuropsychological [10,22,23,31,49] and neuroimaging [7,14,15,18,35] studies have implicated these regions in grammatical processing and computation of morphological agreement.

How differences in the extent of brain damage between the two subjects might relate to their differing performance with nouns and verbs is less apparent. In this section, we will present some reasonable conjectures about the brain regions crucial to processing words of the two categories. We begin by observing that the lesioned area in R.C. is distributed more anteriorly than in J.R.; in general, this datum is consistent with electrophysiological findings which show that comprehension of verbs in their syntactic context elicits increased left anterior positivity compared to noun comprehension [16]. Yet while J.R. presents with damage to large portions of the left parietal lobe, it is interesting that parts of the left middle and inferior temporal cortex usually thought to be associated with object naming are intact.

At the same time, the more posterior structures that are damaged in J.R., like the angular and supramarginal gyri, are sometimes thought to serve as part of a conduit of lexical information from the temporal lobe to frontal areas [19]. Moreover, as we have noted, J.R. does show damage to parts of the left inferior frontal cortex (including Broca's area), despite the finding that he is neither agrammatic nor poor at naming verbs. There is evidence to suggest that this area may play a crucial role in the retrieval of grammatical information about nouns: a study with functional magnetic resonance imaging (fMRI) has shown that when speakers of Italian were asked to make decisions about the gender (a morphosyntactic feature) of target words, parts of the left middle and inferior frontal gyrus were activated, along with left middle and inferior temporal structures traditionally implicated in noun production [33].

Based on the findings reported here and in the other studies discussed above, we speculate that divergent neural systems underlie processing of the grammatical categories of nouns and verbs, and that an important component of each system has its neural substrate in the left frontal cortex. As

[2] In fact, even though English words in many contexts do not bear overt morphological marking, linguists have postulated phonologically null (or "zero") morphemes whose presence is detectable through their syntactic and morphological consequences [37]. It may not be implausible to assume that even words produced in isolation are marked with zero morphology. Certainly in some languages other than English, it is not possible to produce lexical items without bound inflectional morphemes (indicating, for example, tense and agreement on verbs, or case on nouns).

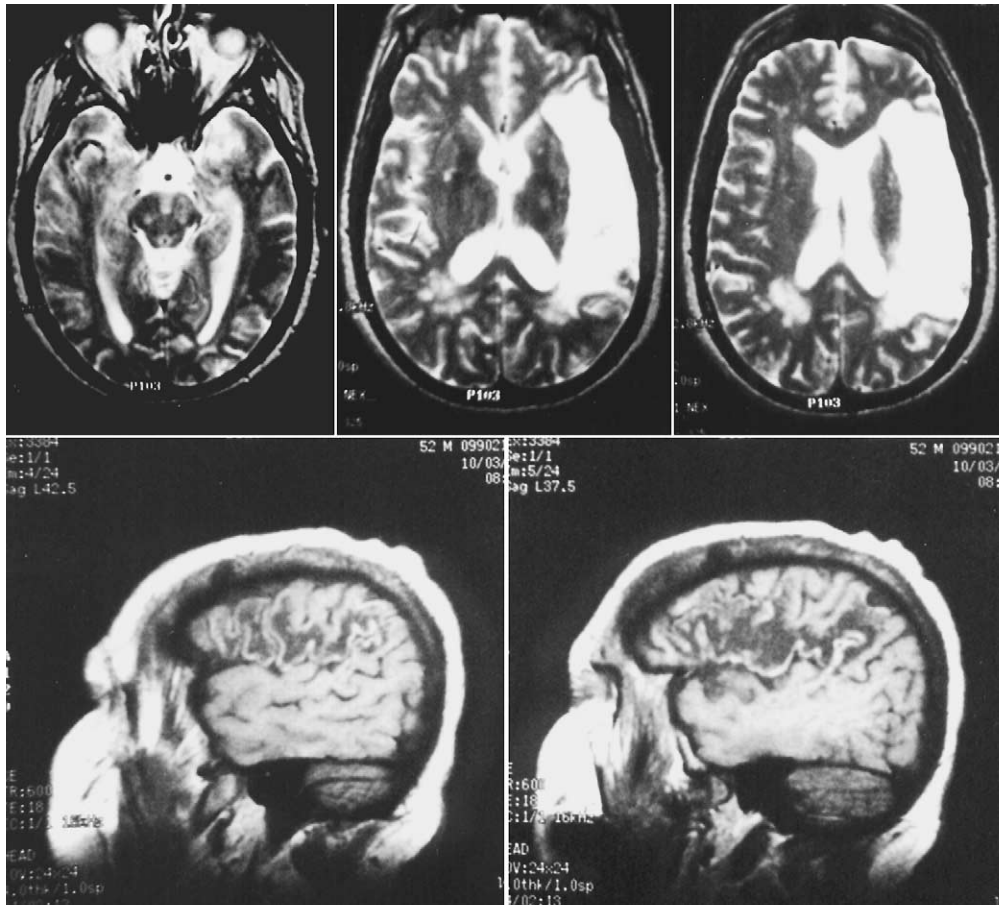

Fig. 2. Representative axial T2-weighted (above) and sagittal T1-weighted (below) MRI sections of the lesion in J.R. The scans reveal a large left middle cerebral artery infarction with damage extending from the frontal lobe posteriorly, including the sensory strip and the angular and supramarginal gyri. The left temporal lobe is largely spared, with the possible exception of the first temporal gyrus near the pole. In addition, J.R. presents with a left cerebellar lesion and parietal lesions bilaterally.

we have mentioned, however, the data do not allow us to decide whether the brain regions involved in language production include separate grammatical processing systems for nouns and verbs, or whether separate streams of lexical information feed into a single central morphosyntactic processor. In J.R.'s case, for example, problems with noun morphology may be due to a loss of noun-specific circuitry (which might be localized in the left frontal cortex), or damage to connections between lexical representations of nouns (in left temporal regions) and a general grammatical processing system (in the left frontal lobe), or even possibly both.[3]

R.C.'s specific problems with verb production may stem from damage to part of the left midfrontal gyrus superior to Broca's area, corresponding to Brodmann area 9. Lesions in this region have been linked to verb retrieval deficits in patients with stroke and neurodegenerative diseases [1,8,13], and neuroimaging studies have shown that left prefrontal/premotor cortex is recruited (along with other parts of the brain) more heavily during verb naming than noun naming [36,38]. However, the significance of this association has been controversial. Citing its proximity to neural circuits known to subserve motor planning, some researchers have proposed that the left prefrontal cortex is activated during the retrieval of action words [43,54], not of verbs as such. Others have noted that left frontal evoked potentials are observed in response to non-action verbs as well as action verbs [16], and a recent study using repetitive transcranial magnetic stimulation (rTMS) showed that suppression of the left prefrontal cortex in normal subjects induces selective delays in responses to verb and pseudo-verb processing tasks very similar to the ones used here [50].

The present study and the results with rTMS both support the conclusion that left prefrontal damage results in an impairment of grammatical knowledge about verbs, and does not affect the production of action words specifically.

[3] Although J.R.'s lesion also extends to parietal areas not thought to play a role in a frontal-temporal circuit, it is unclear whether these areas have ever been implicated in selective noun production deficits. We are aware of only two cases of possible noun deficits arising from damage ostensibly restricted to the left parietal cortex, without frontal or temporal involvement (cases 33 and 54 in [2]); both were reported in the context of a group study, without detailed information about either the patients' neurological lesions or their behavioral patterns of performance.

True action-naming deficits may arise by dint of damage to other brain regions that have been associated with verb production (or to connections between these regions and the left frontal cortex), including parts of the left parietal cortex [52], left mesial occipital cortex and paraventricular white matter underneath the supramarginal and posterior temporal regions [54]. At least some of these areas are probably involved in representing semantic knowledge about actions, and we would not expect patients with lesions confined to these areas to exhibit selective difficulties in the morphological processing of verbs. In the case of R.C., the more posterior neural structures that have been implicated in action naming are largely spared.

4.3. Effects of regularity

The lesion pattern we have described is not atypical for an agrammatic aphasic patient, but it is interesting in light of the finding that R.C. has more difficulty producing irregular forms of verbs than regular forms. According to one influential hypothesis, regular morphological transformations are computed by neural circuits in left frontal brain regions that form part of a putative anterior procedural memory system, while the retrieval of irregular forms is mediated by posterior circuits that subserve semantic memory [55]. It is obviously hard to square R.C.'s performance with this model, which predicts (contrary to our observation) that he should be more impaired at producing regular than irregular morphology.

On the other hand, a recent fMRI study of regular and irregular past-tense formation, intended to corroborate the procedural-semantic model, showed that generating the past-tense of irregular verbs produced differential activation (relative to stem reading) in the left inferior frontal gyrus (BA 44/45) and left middle frontal gyrus (BA 9/46) [45]. These areas largely overlap with R.C.'s lesion, as does the region found to be active in regular past-tense formation (BA 44). The investigators interpreted the inferior frontal activation as reflecting application of the regular past-tense rule, while the midfrontal activation was said to reflect inhibition of the rule. It is not clear whether this particular account is sufficient to explain the pattern of performance observed in R.C.; it seems to predict that more of his errors with irregular verbs should have been of the overregularization (*teached*) type, when in fact R.C. made relatively few such errors.

We suggest that R.C.'s worse performance with irregular morphology is interpreted most parsimoniously as reflecting the greater difficulty of producing irregular forms—either because the computations involved are phonologically less transparent [41,48],[4] or because they require the suppression of an automatic, rule-based process in favor of retrieving alternate word forms from memory [40,42]. What is remarkable is that R.C. makes many fewer errors with nouns than with verbs, and does not have significantly more trouble producing irregular than regular nouns. This again seems to indicate that grammatical category is a crucial principle of neural organization in the left frontal lobe; morphological regularity may not be.

The ability to speak—that is, to continuously produce novel sentences—is a product of mental operations that combine nouns, verbs, and other categories of words into grammatically well-formed phrases. The neural underpinnings of this behavior remain largely unknown, though evidence from acquired disorders of speech production suggests that the left frontal cortex plays a critical role. However, it has been difficult to determine what kinds of linguistic operations are carried out by neural circuits in this part of the brain. In part, this is because previous studies have not distinguished between semantic categories of words (actions and objects) and grammatical categories (nouns and verbs), which constitute distinct kinds of information likely to be utilized at different stages in the process of constructing grammatical sentences. Our results hint that at least some components of the left frontal system may be devoted to processing words of a particular grammatical category.

[4] It may be worth repeating in this context the observation that phonological complexity seems to play an important role in R.C.'s production difficulties; for example, he is worse at producing words with "complex" or syllabic affixes than words with "simple" or non-syllabic affixes.

Acknowledgements

This research was supported by NIH grant DC04245. We thank R.C. for his participation in this study. We are also grateful to J. Finch for administering the repetition test described here, and to G. Miceli, F.M. Mottaghy, M. Gangitano, and A. Galaburda for their help in reading MRI films. Picture-naming stimuli were constructed for the Cognitive Neuropsychology Laboratory by J. Shelton.

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