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Lexical organization of nouns and verbs in the brain

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THE analysis of neuropsychological disorders of lexical processing has provided important clues about the general organization of the lexical system and the internal structure of the processing components[1–3]. Reports of patients with selective dysfunction of specific semantic categories such as abstract versus concrete words[4–6], living things versus inanimate objects[7–11], animals[12–14], fruits and vegetables[15], proper names[16,17] and so forth, support the hypothesis that the neural organization of the semantic processing component is organized in these categories. There are reports of selective dysfunction of the grammatical categories noun and verb[18–21], suggesting that a dimension of lexical organization is the grammatical class of words. But the results reported in these studies have not provided unambiguous evidence concerning two fundamental questions about the nature and the locus of this organization within the lexical system. Is the noun–verb distinction represented in the semantic or in the phonological and orthographic lexicons? Is grammatical-class knowledge represented independently of lexical forms or is it represented separately and redundantly within each modality-specific lexicon? Here we report the performance of two brain-damaged subjects with modality-specific deficits restricted principally (H.W.) or virtually only (S.J.D) to verbs in oral and written production, respectively. The contrasting performance suggests that grammatical-class distinctions are redundantly represented in the phonological and orthographic output lexical components.

H.W. became aphasic due to a stroke (1985) in the parietal region of the left hemisphere (she had earlier suffered a stroke in 1982 in the occipital area). She presented with fluent but paraphasic speech with normal phrase length and intonation. Her selective impairment in comprehending aurally but not visually presented sentences was probably due to a deficit of auditory-verbal short-term memory (repetition span, 3). H.W. showed normal comprehension of both spoken and written words (Peabody Picture Vocabulary Test, PPVT[22]: 153) but oral naming (Boston Naming Test, BNT[23]: 14) and reading were severely impaired. On the Johns Hopkins University Dyslexia and Dysgraphia Batteries (JHU-DDB), her oral reading performance was significantly affected by grammatical word class and frequency, but not by spelling-to-sound regularity or by concreteness or abstractness. Nearly all of her errors were semantically related responses (for example, *dollar* → 'money') or omissions. She wrote all types of words relatively well; her written responses were nearly all legible, although she made many spelling errors (for example, *shake* → 'shaek'); she did not produce semantic paragraphias. H.W. failed to read or write correctly any nonhomophonic nonword (for example, hannee). An earlier analysis of her lexical processing performance confirmed a striking dissociation between oral and written production of words: she produced semantic paraphasias in oral but not written production; and her ability to comprehend the very same words was entirely normal in both modalities[24].

S.J.D. became aphasic in 1985 following a stroke in the left frontotemporal region. Her spontaneous language production and repetition, and her comprehension of spoken and written sentences were very similar to H.W.'s. S.J.D. showed normal comprehension of printed and spoken single words (PPVT: 166). On the JHU-DDB, her writing-to-dictation was significantly affected by grammatical word class and frequency but not by sound-to-spelling regularity or by concreteness or abstractness. Her ability to read (28% correct) and spell (7% correct) nonhomophonic nonwords was severely impaired. Most of S.J.D.'s errors in writing were semantically related responses or omissions; she made no semantic errors in reading. Her relatively infrequent errors in reading were morphological (suffix insertions, deletions or substitutions such as *bowled* → 'bowling') or phonological paraphasias. An earlier analysis of S.J.D.'s lexical processing performance documented a selective deficit in the oral production of morphologically complex words (she read *darken* as 'darkness')[25].

TABLE 1 Performance across lexical production tasks

	N	H.W. Total errors (%)	H.W. Semantic errors (%)	S.J.D. Total errors (%)	S.J.D. Semantic errors (%)
Spoken output					
Reading	296	53	73	2	0
Naming	60	63	81	2	0
Written output					
Dictation	296	0	0	13	64
Naming	60	0	0	50	100

Column 1 reports the total number of stimuli (*N*). The percentage of lexical or omission errors in each task (columns 3 and 5) and the percentage of erroneous responses that resulted in semantic errors are reported for each patient. It may be noted that H.W. produced semantic errors only in oral production tasks and S.J.D. produced semantic errors only in written production tasks. Both patients also produced some morphologically related responses (*hurry* → 'hurried') for which it could not be established whether they represent true morphological or semantic errors. These responses were not scored as semantic errors. H.W. is a 62-year-old right-handed former salesperson; S.J.D. is a 48-year-old, right-handed librarian; strokes were confirmed by CT scan.

In order to document the double dissociation of disproportionate production of semantic errors in oral and written output, the patients were asked to read aloud and to write-to-dictation a set of 296 words. H.W. made semantic errors only in reading; S.J.D. made semantic errors only in writing. The same type of dissociation was observed for oral and written naming of 60 pictured objects and actions: here, too, H.W. made semantic errors only in the oral naming task, and S.J.D. made semantic errors only in the written naming task (Table 1).

The patients' difficulties in oral and written production were not distributed uniformly across nouns and verbs. As may be seen in Table 2, H.W. performed significantly worse in the oral production of verbs than of nouns, but performed equally well in written production of both types of words. By contrast, S.J.D. performed much worse in the written production of verbs than nouns, but performed equally well in the spoken production of both types of words.

Although the reported greater difficulty in brain-damaged subjects to read verbs in comparison to nouns[26] could reflect greater difficulty in processing abstract words[27], this possibility does not apply to all forms of grammatical-class effects. Thus, there are reports of greater difficulty in naming objects than actions[18], ruling out the possibility that grammatical-class effects are always merely the consequence of greater difficulty in processing abstract words. This possibility can also be ruled out in the present case. As reported, neither H.W. nor S.J.D. showed a concreteness or abstractness effect on controlled lists on the JHU-DDB. Additional tests with concrete and abstract nouns matched in frequency and length showed that neither patient had greater difficulty with abstract than concrete words (H.W. reading: 24/38 and 25/38 correct for concrete and abstract nouns, respectively; S.J.D. writing: 36/38 and 35/38 correct for concrete and abstract nouns, respectively). Also, the mean concreteness values of H.W.'s correctly and incorrectly read nouns were 4.94 (s.d. = 1.05) and 5.12 (s.d. = 1.02), respectively (S.J.D made too few errors to support this type of analysis for her performance). Thus, the reported effects for H.W. and S.J.D. are true grammatical-class effects and cannot be attributed to

the differential abstractness of these two classes of words.

It is possible that H.W.'s and S.J.D.'s modality-specific deficit in producing verbs might simply reflect an impairment in producing particular phonological or orthographic forms, and not a deficit in processing words of a particular grammatical category. That is, it could be that S.J.D. has difficulties accessing the specific orthographic representation for the word 'deny' independently of the fact that it is a verb. This possibility can be evaluated by comparing the patients' performance in processing homonyms: words that have the same phonological and orthographic forms (such as crack) but different meanings and grammatical class: a crack, noun; to crack, verb. If the patients' deficit concerned the ability to process specific phonological forms (in the case of H.W.) of specific orthographic forms (in the case of S.J.D.), then we would expect their performance in producing homonyms to be equally impaired independent of the grammatical context in which they are used. By contrast, if the patients' deficit concerned the ability to process words of a specific grammatical class (verbs), then we would expect their performance with homonyms to be poor only when used as verbs despite the fact that they have the same phonological or orthographic form in noun and verb production contexts. The two patients' performance in reading and writing homonyms in noun and verb contexts are shown in Table 3, upper panel: H.W. was selectively impaired in producing the verb form of a homonym only in the reading task, and S.J.D. was selectively impaired in producing the verb form of a homonym only in the writing task. The selective difficulty in producing the verb form of homonyms could not be attributed to a frequency effect since the grammatical class-specific impairment persisted even when the verb form of a homonym is more frequent than the noun form (Table 3, lower panel).

The contrasting patterns of modality-specific and grammatical category-specific impairments reported for H.W. and S.J.D. severely constrain plausible hypotheses about the loci of functional damage to the lexical processing system that may be responsible for these patients' word production impairments,

TABLE 2 Percentage correct performance combined for all oral and written production tasks

	H.W.		S.J.D.	
	Nouns	Verbs	Nouns	Verbs
Oral production	56	22	99	97
Written production	99	99	99	70

H.W. performed worse in oral production of verbs than of nouns ($\chi^2=34.3$; $P<0.001$), and S.J.D. performed worse in written production of verbs than nouns ($\chi^2=40.7$; $P<0.001$). H.W.'s written production and S.J.D's oral production of verbs and nouns were virtually flawless. The performance reported here was obtained by collapsing across several tasks described below. In reading and writing sets of nouns and verbs matched in frequency and length ($N=98$, in each set) a dissociation was observed between grammatical classes: H.W. read correctly 46/98 (47%) nouns and 19/98 (18%) verbs, and, ignoring spelling errors (*moose* → 'mosse'; *sneeze* → 'snezze'), she wrote correctly all nouns and verbs; S.J.D. wrote correctly all 98 nouns and 74/98 (76%) verbs, whereas, ignoring pronunciation and morphological errors (*sleeve* → 'sleeves'; *dangle* → 'dangly'), she read correctly 96/98 (98%) nouns and 93/98 (95%) verbs. A similar pattern of performance was obtained for the two patients in oral and written naming of pictures depicting objects (nouns) and actions (verbs; $N=30$ in each word class) whose names were matched in frequency and length: H.W. named correctly 16/30 (53%) objects and 6/30 (20%) actions and, ignoring spelling errors, she wrote correctly all but one noun and one verb; S.J.D. wrote correctly 29/30 (97%) objects and 16/30 (53%) actions, and she named correctly all objects and all but one action. Although relatively few observations are available for sentence production tasks, the results are perfectly consistent with those obtained with single-word processing tasks: H.W. correctly produced 7/12 (58%) verbs in comparison with 23/24 (96%) nouns in oral production; S.J.D. correctly produced 4/6 verbs in comparison with 19/19 nouns. Both patients performed flawlessly for both verbs and nouns in their unimpaired modality (H.W. writing: 3/3 and 6/6 for verbs and nouns, respectively; S.J.D. speaking: 8/8 and 21/21 for verbs and nouns, respectively).

TABLE 3 Oral and written production of homonyms in sentence contexts

	H.W.		S.J.D.	
	Oral reading	Writing	Oral reading	Writing
Nouns	44/50 (88)	49/50 (98)	50/50 (100)	49/50 (98)
Verbs	23/50 (46)	48/50 (96)	50/50 (100)	28/50 (56)
Nouns	19/20 (95)	19/20 (95)	20/20 (100)	20/20 (100)
Verbs	8/20 (40)	19/20 (95)	20/20 (100)	17/20 (85)

In the written version of this task, the patients were dictated a sentence and asked to write the emphasized (and subsequently repeated) word in the blank space in a typed sentence. For example, for the noun form of *crack*, the stimulus was: "There's a *crack* in the mirror; write 'crack'"), and the patient was required to write the word crack in the sentence frame *There's a _____ in the mirror*; for the verb form, the stimulus was: "Don't *crack* the nuts in here; write 'crack'", and she was required to write the word crack in the frame *Don't _____ the nuts in here*. The reading version of the task simply required the patients to pronounce the underlined word in a sentence (*There's a crack in the mirror*; *Don't crack the nuts in here*) after reading the sentence silently. The upper panel reports the number and percentage (in parentheses) for correct responses in oral reading (columns 1 and 3) and writing to dictation (columns 2 and 4) for the noun and verb forms of homonyms (for example, a crack or to crack). It is clear that the two patients are selectively impaired in producing the verb form of homonyms in only one modality of output, oral and written for H.W. and S.J.D., respectively. The lower panel reports performance only for the subset of stimuli in which the verb form is more frequent than the noun form, ruling out the possibility of a frequency effect as the basis for the selective deficit of the verb form of homonyms.

and they provide clear evidence for the hypothesis that knowledge of the phonological and orthographic forms of words is organized by grammatical category.

(1) The fact that the two patients produced semantic errors only in one modality of output (speaking or writing), independent of whether the input was a word or a picture, and the fact that both patients showed normal comprehension of single words rule out the possibility that the lexical impairment in these patients results from a deficit to input lexical representations or to the semantic component. Instead, these facts suggest that the locus of functional deficit is at a level where lexical phonological representations (for H.W.) and lexical orthographic representations (for S.J.D.) are specified for output, either because of damage directly to modality-specific lexical representations or because of damage to access of those representations. This conclusion implies the seemingly counterintuitive possibility that semantic errors can arise from damage to processes at the level of phonological and orthographic output representations[24,28].

(2) The facts in (1), which establish that the locus of functional deficit in H.W. and S.J.D. is respectively at the level where phonological and orthographic lexical forms are computed for output, and the fact that verbs were selectively impaired in a single modality of output in each patient together rule out the possibility that the deficit in these patients concerns a specific grammatical category in a modality-independent lexical component. These results suggest, instead, that the deficit concerns the activation of the category verb in modality-specific lexical components, again either because of damage directly to modality-specific lexical representations or because of damage to access of these representations. The implication of this conclusion is that phonological and orthographic output representations are organized by grammatical category.

(3) Finally, the facts in (1) and (2) and the fact that H.W. and S.J.D. were impaired in processing only the verb form of homonymic words imply that the deficit does not concern specific lexical forms (for example, the orthographic form *crack*) but the grammatical category verb (of which *crack* is an instance) for modality-specific lexical forms. One implication of this latter conclusion is that we should give serious consideration to the possibility that grammatical category information is repre-

sented separately and redundantly in each modality-specific lexical system.

In summary, taken together with recent results of category-specific deficits, the results we have reported suggest a remarkably specific organization of lexical knowledge in the brain, both at the semantic[3] and at the lexical form levels. Although at this time we do not have clear hypotheses about the nature of the brain mechanisms that compute lexical structure, it is clear that the information computed by these mecha must represent not only the phonological and orthograp form of words but also their grammatical class. The results reported for H.W. and S.J.D. pose a serious challenge for those models of lexical processing that would dispense with linguistic level information in the representation of lexical knowledge[29].

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