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Hemispheric differences in grammatical class: A hemifield investigation

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Although a number of studies have examined lexical asymmetries in hemispheric processing, few have systematically investigated differences between nouns and verbs. Lateralization effects of grammatical class were examined by presenting nouns and verbs of both high and low frequencies to either the right or left visual field. Results from a noun/verb categorization task revealed a significant visual field by grammatical class interaction: Verbs were processed faster in the left compared to the right hemisphere, while there was no hemispheric advantage for the processing of nouns. The present study provides new evidence for the role of grammatical class in lexical processing. These behavioral results, in combination with imaging data from fMRI (Pugh et al., 1997), suggest that lexical knowledge is organized so that representations of different grammatical categories are processed by different brain mechanisms.

1 Introduction

The salience of hemispheric asymmetries in the processing of grammatical class is explored in this paper. Anatomically, there is evidence for hemispheric asymmetries in adults, in infants, and even in the fossil record (Geschwind and Galaburda 1987). Behaviorally, these asymmetries have also been noted (see Hellige (1993) for a review). Traditionally, the left hemisphere was characterized as dominant, focused on language, while the right hemisphere was subordinate and mute. Modifications of this view emphasized differences in the manner in which the two hemispheres treat incoming information: processing in the left hemisphere was more analytic, sequential, and involved in linguistic analysis whereas the right hemisphere was holistic, with acute visual spatial skills, and sensitive to processing melody and intonation. A more contemporary characterization suggests a distinction based on computational styles, with fine coding of information and categorical judgments attributed to the left hemisphere and coarse coding and coordinate analyses to the right hemisphere (e.g., Beeman 1994; Kosslyn, Koenig, Barrett, Cave, Tang and Gabrieli 1989). In all conceptualizations, it is clear that the right and left hemispheres function differently.

A much debated question regarding hemispheric processing of language is whether there are differences in lexical processing - namely, whether both hemispheres have access to similar lexicons. Early research suggested that the right hemisphere accessed only a small set of high frequency, highly imageable, concrete, content words. However, some recent research has shown a different pattern of results. Chiarello (1988), for example, concludes that word frequency effects appear to be constant across the hemispheres. Moreover, when word frequency is controlled, there are few differences in the processing of content and function words. Neither have consistent differences been shown in terms of the lexical variables of abstractness and imageability. Overall, then, recent research questions a simplistic notion of unequal lexicons across the hemispheres based on frequency, imageability or content/function class distinctions.

A potentially more productive characterization of hemispheric differences in lexical processing may be found in differences in grammatical class - specifically, between nouns and verbs. Rarely, however, have noun/verb distinctions been examined in processing. Most psycholinguistic studies use only nouns, or don't analyze nouns and verbs separately.

Some of our own research has scrutinized the noun-verb distinction in more detail, investigating a number of distinguishing characteristics of nouns in contrast to verbs. Sereno and Jongman (1990) and Sereno (1994) obtained data supporting a phonological distinction between nouns and verbs in English. A lexical analysis of the Brown Corpus (Kucera and Francis 1981) revealed a skewed distribution in which the syntactic classes of noun and verb are distinguished in terms of the phonological classification of the stressed vowel. This distinction was shown as well to have perceptual consequences, with subjects processing nouns with back vowels and verbs with front vowels faster, a finding that generalized over tasks (lexical decision, noun/verb categorization). These results suggest that subjects are sensitive to grammatical class differences and that syntactic class may be a parameter that structures lexical space.

A number of studies have also examined lexical stress differences between nouns and verbs. Lexical analysis of English has revealed that most bisyllabic nouns in English are forestressed whereas most bisyllabic verbs are backstressed (Kelly 1988; Kelly and Bock 1988; Sereno 1986). Sereno and Jongman (1995) analyzed bisyllabic words in English that can be used as either a noun or a verb (words such as *answer* or *design*). They found consistent acoustic differences in speakers' production of these syntactically ambiguous words contingent upon their function as a noun or verb.

Significant differentiation between nouns and verbs at a number of linguistic levels raise the possibility of detectable neuropsychological differences in processing. A few studies in the late 1970s did compare nouns and verbs experimentally across either visual half-field. Words were varied in terms of imageability, concreteness, grammatical class, or frequency, using either lexical decision or naming tasks.

In particular, Hines (1976) evaluated visual half-field recognition for high and low frequency verbs, abstract nouns, and concrete nouns. His most significant finding was an interaction between visual half-field, word class, and frequency. Subjects more easily recognized abstract high-frequency nouns presented in the right visual half-field and concrete high-frequency nouns in the left visual half-field. Unfortunately, low levels of accuracy obtained, possibly due to short stimulus exposure time (20 ms) or, as Hines himself noted in a later study (1977), because the sample of words could not be generalized (stimuli were treated as a fixed effect).

In a later study that included equal numbers of nouns and verbs, Shanon (1979) reported no significant interactions. However, field presentation was not balanced. Day (1979) also conducted a similar experiment, but added adjectives as a third grammatical class and controlled for visual-field presentation. Within each of the noun, verb, and adjective groups, half of the words were high imagery words and half were low imagery words. Results suggested a right visual half-field advantage for low imagery nouns and adjectives and high and low imagery verbs, but not for high imagery nouns and adjectives. Day theorized that the right hemisphere may be capable only of recognizing words high in imagery. However, no statistically significant interaction between visual half-field and syntactic class was reported.

Although some of these reports claimed that syntactic class affected hemispheric processing, caution must be used in interpreting the results. These studies were problematic in several respects. In many cases, stimuli didn't appear in both visual fields. Error rates of approximately 50% were often reported, and reaction times were on the order of 1500-2000 ms. Finally, some authors claimed an effect of visual field without reporting the crucial interaction statistics. Thus, these previous studies do not substantiate the claim that lateralization of grammatical class occurs.

While more recent studies have shown that there are no significant differences in imageability or frequency between the hemispheres (for a review, see Chiarello (1988)), grammatical class differences have not been re-examined under rigid testing procedures, and that was the incentive for the present study. Based on prior results from our laboratory, we fully expected that reaction times for nouns would be shorter than those for verbs in either visual half-field. The present study sought to extend this finding by investigating whether these grammatical class differences are lateralized.

2 Method

Forty-four 4-letter words were selected as stimuli. Nouns and verbs were each divided into high and low frequency groups. Noun and verb groups were matched for frequency (mean log frequency of high-frequency nouns and verbs was 2.38 and 2.27, respectively; mean log frequency of low-frequency nouns and verbs was .98) and mean number of syllables (1.1 across all four groups). Average concreteness and imagery ratings, respectively, for high frequency nouns (500, 501), low frequency nouns (386, 383), high frequency verbs (292, 327), and low frequency verbs (40, 125) were taken from the MRC Psycholinguistic Database (Coltheart 1981; Wilson 1988). Half of the words were exemplary nouns, with no occurrences as verbs in the Brown Corpus; and half of the words were exemplary verbs, with no occurrences as nouns.

A noun/verb categorization task was used in which participants were to decide whether each stimulus was a noun or verb. A response was recorded by a button press with the right index finger centered between the noun and verb buttons. Button order was counterbalanced across subjects.

Each trial started with a central fixation cross presented for 500 ms. Immediately following fixation, stimuli were presented unilaterally for 183 ms (screen refresh rate is 60 Hz) in lower case letters in horizontal orientation. Each stimulus was presented twice: once in the left visual field and once in the right visual field. Order of presentation was randomized. The center of each word was displaced 2.5^{o} to the left or right of the center of the computer screen. Stimuli were presented at a fixed rate with an SOA of 2.5 seconds. Response time was measured from the onset of the target word until a noun/verb categorization response was made.

Thirty-eight college students (15 males and 23 females) participated in the experiment. They were all right-handed native speakers of English.

3 Results

Results consisted of reaction time and error data. Both subject and item analyses were conducted. We anticipated a possible gender effect; however, a first analysis revealed no main effects or interactions involving participant gender. Nor were there any main effects or interactions involving button order. Hence, these variables were not considered in subsequent analyses.

A repeated measures ANOVA with Visual Field, Frequency, and Grammatical Class was conducted on both the reaction time and error data. A main effect of Visual Field ([$F1(1,37) = 5.23$, $MSe = 1868$, $p = .028$]; [$F2(1,40) = 5.57$, $MSe = 637$, $p = .023$]) indicated that responses were significantly faster to stimuli presented to the right visual field (746 ms) compared to the left visual field (757 ms). The literature has consistently shown that when words are briefly presented to the left or right of fixation, performance is often asymmetrical, with faster and more accurate responses to stimuli presented in the right visual field. The interpretation of this typical result ranges from a scanning bias to the processing style of the hemisphere that is initially activated.

A main effect of Frequency ([F1(1,37) = 31.30, MSe = 2364, p = .000]; [F2(1,40) = 11.22, MSe = 2063, p = .002]) revealed that responses were significantly faster to high-frequency stimuli (736 ms) than to low-frequency stimuli (767 ms). This is also an expected effect, since high frequency stimuli had an average frequency of occurrence of approximately 300 per million and low frequency stimuli 10 per million. This frequency effect was evident in both the left and right visual fields.

A main effect of Grammatical Class ([F1(1,37) = 8.12, MSe = 4896, p = .007]; [F2(1,40) = 5.00, MSe = 2063, p = .031]) indicated that nouns (740 ms) were responded to significantly faster than verbs (763 ms), a result we have consistently obtained in our experiments. Sereno and Jongman (1997) attribute this effect to differences in inflectional structure between nouns and verbs in English - nouns occur more frequently as uninflected forms.

In addition to the main effect of Grammatical Class, there was also a Grammatical Class by Frequency interaction ([F1(1,37) = 18.29, MSe = 1823, p < .001]; [F2(1,40) = 5.21, MSe = 2063, p = .028]). As shown in Figure 1, nouns and verbs differed across frequency of occurrence.

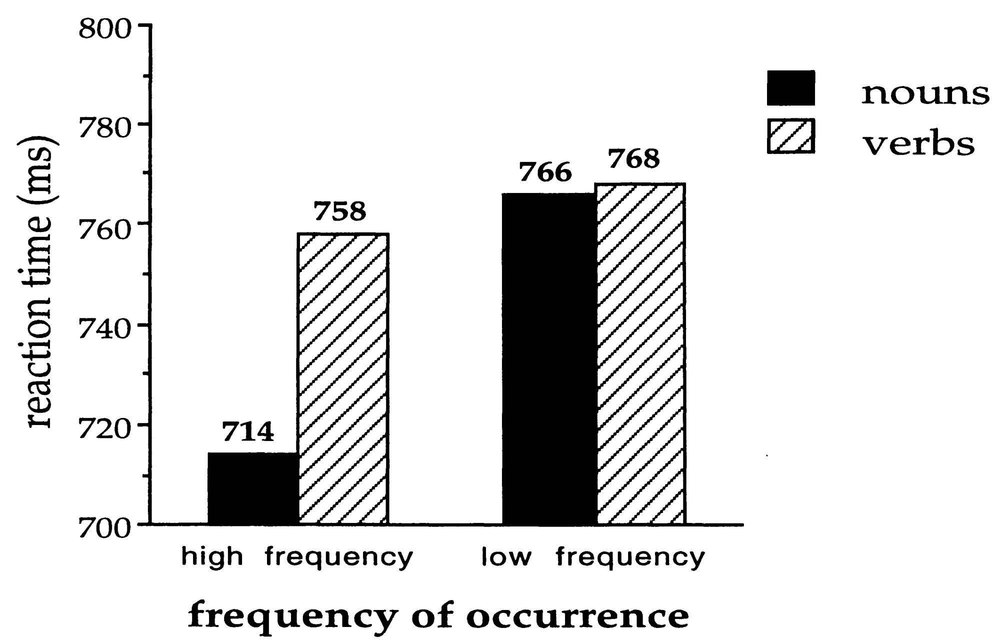

Figure 1 Response latencies (in ms) to nouns and verbs as a function of frequency of occurrence.

High-frequency nouns were 44 ms faster than high-frequency verbs while response times to low-frequency stimuli showed only a non-significant 2 ms difference. If frequency differences associated with inflectional differences produce this grammatical class effect, differences should be more prominent in high frequency words because absolute differences in uninflected frequency are relatively greater for high frequency stimuli. This is indeed the pattern that obtained.

Finally, the most intriguing finding of the present study was the significant interaction between Visual Field and Grammatical Class ([$F1(1,37) = 9.57$, $MSe = 1530$, $p = .004$]; [$F2(1,40) = 6.57$, $MSe = 637$, $p = .014$]). As shown in Figure 2, nouns and verbs differed across the two hemispheres. Simple effects analyses revealed that response times to verbs presented to the right visual field were 25 ms faster compared to the left visual field. For nouns, there was a non-significant 3 ms difference between hemispheres.

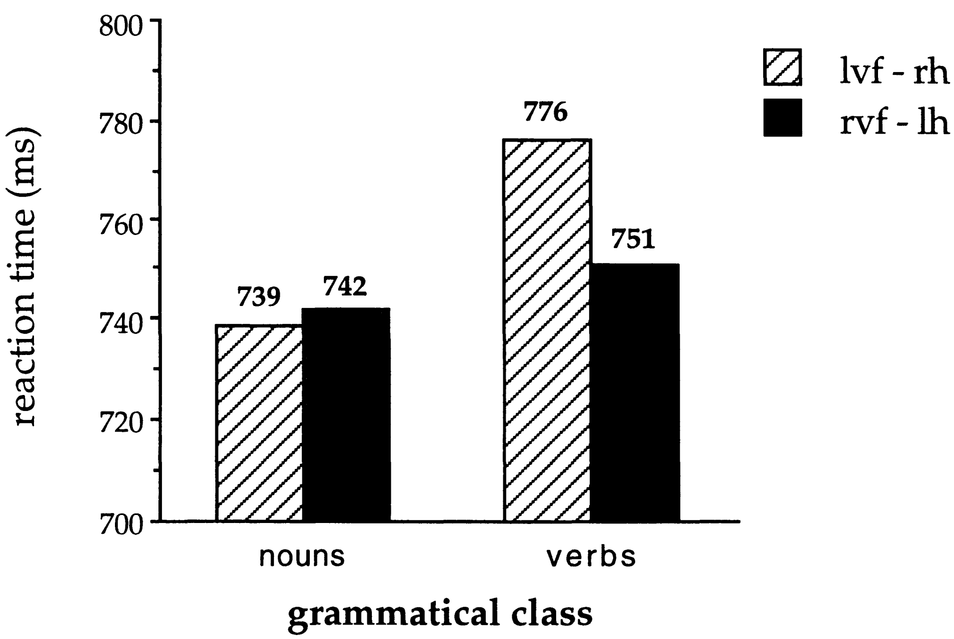

Figure 2 Response latencies (in ms) to nouns and verbs as a function of visual field. Lvf and rvf indicate the left and right visual fields, respectively.

Recall that our earlier study indicated that overall grammatical class differences may be due to simple frequency differences of uninflected forms. However, grammatical class differences *across hemispheres* cannot be attributed to frequency differences in the present study since frequency of occurrence differences did not turn up across hemispheres, either by interacting with Visual Field or as a three-way interaction with Visual Field and Grammatical Class. Grammatical class alone showed a significant processing difference across hemispheres.

In order to determine whether imageability and/or concreteness affected the present results, an ANCOVA was conducted with imageability and concreteness as covariates. Imageability and concreteness norms were taken from the MRC Psycholinguistic Database (Coltheart 1981; Wilson 1988). Results indicated that the interaction of Visual Field by Grammatical Class still obtained [$F(1,40) = 6.57$, $MSe=4187$, $p= .014$].

A repeated measures ANOVA with Visual Field, Frequency, and Grammatical Class was conducted on the error data. Two main effects were observed. A main effect of Frequency ([$F1(1,37)=15.06$, $MSe=11$, $p<.001$]; [$F2(1,40)=6.59$, $MSe=38$, $p=.014$]) indicated that there were more errors to low frequency stimuli (148 errors) than to high frequency stimuli (90 errors). A main effect of Grammatical Class ([$F1(1,37)=9.08$, $MSe=8$, $p<.005$]; [$F2(1,40)=4.90$, $MSe=28$, $p=.033$]) revealed that there were more errors to verb stimuli (144 errors) than to noun stimuli (94 errors). The error results are consistent with the reaction time data.

4 Discussion

The present experiment demonstrates significant differences in the processing of nouns and verbs across the hemispheres. Further analyses revealed that there were significant processing differences across hemispheres for verbs but not for nouns. Response times to verbs presented to the right visual field were 25 ms faster compared to the left visual field. In additon, main effects of visual field (stimuli presented to RVF faster compared to LVF), frequency (high frequency stimuli faster than low frequency stimuli), and grammatical class (nouns faster than verbs) were observed. A further significant finding was an interaction between grammatical class and frequency, with differences showing up between high frequency nouns and verbs but not for low frequency stimuli. The lack of a three-way interaction with visual field and additional analyses revealing that imageability and concreteness cannot account for the observed hemispheric differences further support a critical role for grammatical class.

The most intriguing implication of the present findings concerns the overall organization of brain systems for language. The findings lend support to the notion that there are distinct systems for nouns and verbs. Such a conclusion is supported by the growing body of research showing a dissociation between noun and verb production and comprehension in brain-damaged patients. These studies (e.g. Damasio and Tranel 1993;

Koenig, Wetzel and Caramazza 1992; Miceli, Silveri, Nocentini and Caramazza 1988; Miceli, Silveri, Villa and Caramazza 1984; Zingeser and Berndt 1988, 1990) have documented patients with relatively selective noun or verb production as well as comprehension impairments. Specifically, agrammatic aphasics show deficits in verb retrieval, while anomic aphasics show deficits in noun retrieval. These selective deficits in processing are sometimes restricted to a single output modality, that is, spoken versus written output (Caramazza and Hillis 1991).

Recently, Damasio, Grabowski, Tranel, Hickwa and Damasio (1996) have begun to investigate the implications of such an organization in normal unimpaired individuals. In a PET word retrieval experiment, Damasio et al. showed differential activation of brain sites for categories of nouns. These results suggest some form of categorical organization for grammatical class at the lexical level of representation.

Support for a hemispheric role in lexical organization may also be gained from investigating split-brain patients (see, for example, Baynes (1990)). In split-brain patients, the neural pathway which connects the two hemispheres is severed in order to minimize the transfer of epileptic seizures. Preliminary data from one patient show faster processing of verbs in the left hemisphere, similar to the present results with an unimpaired population.[1]

The recent functional neuroimaging data of Pugh, Shaywitz, Shaywitz, Constable, Fulbright, Sudlarski, Mencl, Lacadie, Shankweiler, Katz, Fletcher, Marchione and Gore (1997) further support the present hypothesis by indicating a relatively greater left hemisphere involvement in the processing of verbs relative to nouns. In the Pugh et al. (1997) study, noun and verb differences were observed in the superior temporal gyrus region, and smaller effects show up in inferior frontal gyrus and extrastriate regions. Verbs were associated with greater left hemisphere activation compared to nouns while nouns showed a greater right hemisphere involvement. These differences were observed in both a lexical decision and naming task.

In sum, the present data from unimpaired individuals, additional results from impaired populations, and recent imaging results provide initial evidence for the hypothesis that lexical knowledge is organized in the brain so that representations of different grammatical categories are processed by widely distributed brain structures or mechanisms.

[1] These data were collected in collaboration with Kathy Baynes. Additional patients are being tested to corroborate these results.

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