Published in final edited form as:
Brain Res. 2006 April 7; 1081(1): 191–202. doi:10.1016/j.brainres.2006.01.058.

To mind the mind: An event-related potential study of word class and semantic ambiguity

Chia-lin Lee[a,*] and **Kara D. Federmeier**[a,b,c]

[a]Department of Psychology, University of Illinois, Urbana-Champaign, IL 61820, USA

[b]Neuroscience Program, University of Illinois, Urbana-Champaign, IL 61820, USA

[c]The Beckman Institute for Advanced Science and Technology, University of Illinois, Urbana-Champaign, IL 61820, USA

Abstract

The goal of this study was to jointly examine the effects of word class, word class ambiguity, and semantic ambiguity on the brain response to words in syntactically specified contexts. Four types of words were used: (1) word class ambiguous words with a high degree of semantic ambiguity (e.g., 'duck'); (2) word class ambiguous words with little or no semantic ambiguity (e.g., 'vote'); (3) word class unambiguous nouns (e.g., 'sofa'); and (4) word class unambiguous verbs (e.g., 'eat'). These words were embedded in minimal phrases that explicitly specified their word class: "the" for nouns (and ambiguous words used as nouns) and "to" for verbs (and ambiguous words used as verbs). Our results replicate the basic word class effects found in prior work (Federmeier, K.D., Segal, J.B., Lombrozo, T., Kutas, M., 2000. Brain responses to nouns, verbs and class ambiguous words in context. Brain, 123 (12), 2552–2566), including an enhanced N400 (250–450ms) to nouns compared with verbs and an enhanced frontal positivity (300–700 ms) to unambiguous verbs in relation to unambiguous nouns. A sustained frontal negativity (250–900 ms) that was previously linked to word class ambiguity also appeared in this study but was specific to word class ambiguous items that also had a high level of semantic ambiguity; word class ambiguous items without semantic ambiguity, in contrast, were more positive than class unambiguous words in the early part of this time window (250–500 ms). Thus, this frontal negative effect seems to be driven by the need to resolve the semantic ambiguity that is sometimes associated with different grammatical uses of a word class ambiguous homograph rather than by the class ambiguity per se.

Keywords

Language; Word class; Word class ambiguity; Noun–verb homonymy; ERP

1. Introduction

Nouns and verbs have been one of the intensively studied topics in psycholinguistics and neurolinguistics, and many studies using different paradigms and different participant populations have shown that these two word classes are treated differently. In children's early lexical development, for example, there is an advantage for learning nouns over verbs (Gentner, 1982). Even as adults, people tend to remember nouns better than verbs (Reynolds and Flagg, 1976; Thios, 1975; Wearing, 1973). Moreover, in tasks requiring the paraphrasing of sentences

*Corresponding author. E-mail address: clee26@uiuc.edu (C. Lee).

or the translation of sentences across languages, nouns tend to be less mutable in meaning than verbs (Gentner, 1981).

In addition, neurolinguistic research has shown that these two parts of speech can be selectively compromised in different aphasic populations in both connected speech production and picture naming (Berndt and Zingeser, 1991; McCarthy and Warrington, 1985; Miceli et al., 1984, 1988; Myerson and Goodglass, 1972; Zingeser and Berndt, 1990).Aphasic patients with more frontal lesions (e.g., with Broca's aphasia) tend to have greater difficulties with verbs, while aphasic patents with more posterior damage (e.g., with Wernicke's aphasia and anomia) tend to have greater difficulties with nouns. Noun/verb differences have also been seen in other neurological populations. Research has shown that patients with frontal or frontotemporal degenerative diseases, such as frontotemporal dementia, Alzheimer's disease, or HIV-1 infection, have particular difficulties naming or spontaneously generating action verbs or using pseudo-words as verbs (Shapiro and Caramazza, 2003; Woods et al., 2005). On the other hand, patients with atrophy of the left temporal lobe have more difficulty producing and comprehending nouns than verbs (Daniele et al., 1994).

Word class effects reported in these behavioral and neuropsychological studies have sometimes been taken as evidence for separate representations (or neural processing systems) for nouns and verbs. However, results of online neurophysiological measurements from brain-intact participants have been mixed. In studies measuring brain metabolic activity in healthy participants, the kind of double dissociations reported with patients have not manifested. Several studies have failed to find word class effects of any kind. For example, Tyler et al. (2001, PET) found no significant activation differences for nouns and verbs in both a lexical decision task and a semantic categorization task. Similarly, in a study done in Chinese, nouns and verbs were found to activate a wide range of overlapping areas, with no area exclusively responding to either word class (Li et al., 2004, fMRI). Other studies have reported areas that are specifically engaged by items from a particular word class but have failed to find double dissociations. Warburton et al. (1996, PET), using a noun/verb generation task, found little difference between the two word classes, though some temporal and parietal areas activated only for verbs. Perani et al. (1999, PET) used a lexical decision task and reported a slightly different set of areas (dorsolateral frontal and lateral temporal cortex) that were specific for verb processing; again, however, there were no brain areas more active for nouns. Still, another study found that bare nouns and verbs did not elicit distinct patterns of brain activity but that word class differences arose when nouns and verbs were inflected, with left inferior frontal gyrus more strongly activated in processing inflected verbs than inflected nouns (Tyler et al., 2004, fMRI).

Studies measuring magnetic or electrical brain activity have also yielded results that are inconsistent across experiments and across languages. Soros et al. (2003) used magnetoencephalography (MEG) to monitor brain responses during object and action naming in normal adults and one anomic patient, who was more impaired at naming nouns than verbs. Their results showed that, for normal participants, the cortical activity associated with naming object nouns and action verbs was very similar in both space and time. Word class dissociations were observed only for the patient, with more activation in Broca's area, left middle temporal cortex, and left superior parietal cortex for object naming than action naming, and more activation in left inferior parietal lobe for action naming than object naming. Osterhout et al. (1997) also found no word class differences in healthy young adults' event-related potential (ERP) responses to English nouns and verbs read in passages. In contrast, Brown et al. (1999), using a similar paradigm in Dutch, found a word class effect between 250 and 550 ms post-stimulus-onset, with more negativity to verbs than to nouns over all electrodes, with the difference larger over the back of the head. Several other studies have also reported word class differences in a similar time frame, but with different scalp distributions. Dehaene (1995), using a semantic categorization task, found distributional differences among word categories around 260 ms, with a left temporo-parietal negativity for verbs (but also for animal names) and other topographies for different subsets of nouns (a left inferior temporal negativity for proper names and a bilateral positivity for numerals). In a series of studies conducted in German using nouns and verbs in a lexical decision task (Preissl et al., 1995; Pulvermuller et al., 1996, 1999a), word class differences have been reported beginning around 200 ms, with enhanced responses to verbs over fronto-central (possibly motor and premotor) areas and enhanced responses to nouns over occipital (possibly visual) areas. In addition to this early difference, Pulvermuller and colleagues have found that, between 500 and 800 ms, the spectral response around 30 Hz was enhanced for verbs at central sites but was stronger for nouns at sites over visual cortical areas (Pulvermuller et al., 1999a).

As suggested by Federmeier et al. (2000), there are a number of possible explanations for the inconsistent patterns observed across methods and studies. First, many studies reporting word class differences have used concrete nouns and action verbs as their experimental stimuli. These word types are only subsets of their grammatical categories, and the distinction between them strongly covaries with semantics (sensory features and motor associations). Therefore, it might not be surprising if effects seen with these items were not apparent when nouns and verbs were compared more generally. Second, most experiments have presented nouns and verbs in isolation, without any syntactic context, and have used lexical decision or picture naming tasks that do not require much linguistic analysis or syntactic integration of the target words; these factors may have reduced the visibility of any word class effects. Finally, Federmeier et al. (2000) emphasized the importance of controlling for word class ambiguity when examining word class effects. Brown and colleagues found that word class ambiguous words engage different brain areas when used as nouns than as verbs, with more frontal positivity and posterior negativity for nouns (Brown et al., 1973, 1976, 1980). However, this factor has rarely been controlled for or even examined and could be an important source of cross-linguistic differences, since languages vary widely in the extent to which lexical items can be class ambiguous.

To try to address these points, Federmeier et al. (2000) conducted an ERP study using nouns and verbs from semantic domains not restricted to objects and actions. Class unambiguous nouns (e.g., “beer”) and verbs (e.g., “eat”) were used, along with word class ambiguous items (e.g., “drink”). Target words were embedded within sentences with syntactically specified leading contexts (e.g., “Jane wanted to/the…”); these contexts thus specified how ambiguous items were being used. Several effects of both word class and word class ambiguity were observed. Responses to nouns were more negative than those to verbs between 250 and 450 ms over central–posterior sites (on the N400 component). Verbs also elicited a left frontal positivity from 200 to 400 ms, but only if they were word class unambiguous (class ambiguous words in verb-predicting contexts, e.g., “Jane wanted to drink…”, did not elicit this effect) and only when these unambiguous verbs were appropriately used in a verb-predicting context. Finally, in comparison with unambiguous words, class ambiguous words elicited a slow, frontal negativity starting from about 200 ms after word onset and continuing into the presentation of the next word. Thus, while Federmeier et al. (2000) did observe noun/verb differences, they also found that word class ambiguity was an important determinant of the pattern of brain activity elicited by a word, even when that word was in a syntactically well-specified context. This finding is bolstered by recent data from Tranel et al. (2005, PET), showing that brain activations differ for word class ambiguous and unambiguous items even when used as the same word class. In this study, subjects were shown color photographs of tools and actions and were told to say the stem form of the single word that denotes that particular picture. The pictures were manipulated so that they were to be named with non-homonymous nouns (e.g., ‘camera’) or verbs (e.g., ‘juggle’) or homonymous nouns (e.g., ‘comb’) or verbs (e.g., ‘comb’). Results of action naming and object naming were compared to a baseline task that required subjects to say ‘up’ or ‘down’ to the orientation of black-and-white pictures of unfamiliar faces. Both unambiguous nouns and class ambiguous items used as nouns activated left inferotemporal areas, but the ambiguous words used as nouns additionally activated the left frontal operculum. Verbs, irrespective of ambiguity, were associated with activation in left inferotemporal, left frontal opercular, and left posterior middle temporal areas; however, ambiguous items used as verbs activated the latter two areas to a lesser extent than did unambiguous verbs. Taken together, data from these studies show that, even when used similarly, word class ambiguous and unambiguous items engage somewhat different neural resources.

One factor that might make the processing of word class ambiguous items more difficult is the fact that some – though not all – word class ambiguous items are also semantically ambiguous. In English, some homophonous nouns and verbs are very similar in terms of their meanings (e.g., “nap”), while others are quite different (e.g., “duck”). Goldberg and Goldfarb (2005) reported that in English approximately one fifth of class ambiguous words have unrelated noun and verb meanings. We found a similar distribution in a rating study of 433 class ambiguous words (described below). On a 7-point rating scale, with lower numbers indicating greater dissimilarity between the noun and verb senses of the word, about one-third of the ambiguous items had an average rating of less than 3.5. Since this factor was not systematically manipulated or controlled for, it is possible that some or all of the word class ambiguity effects observed by Federmeier et al. (2000) and Tranel et al. (2005) could have been due to semantic, rather than just word class, ambiguity.

There is a large literature on lexical/semantic ambiguity, only a small portion of which has dealt with lexically ambiguous words whose meanings fall into different word categories. The focus of the literature at large has primarily been on whether semantically ambiguous words (homographs) are processed differently from unambiguous words and how meaning retrieval of ambiguous words is affected by prior context (see review by Van Petten, 2002). The literature suggests that certain aspects of word recognition may be facilitated for words with multiple meanings (as seen in, for example, word naming tasks, lexical decision tasks, and definition generation tasks) (Jastrzembski, 1981; Jastrzembski and Stanners, 1975; Kellas et al., 1988), while meaning selection or phoneme monitoring may often (or always) be more difficult for these words (Cairns and Kamerman, 1975; Hino et al., 2002). Most studies looking at the role of context in modulating meaning access for ambiguous words have used the context–ambiguity–probe paradigm (CAP, described below), though some eyetracking and ERP studies have managed to directly analyze the processing of the ambiguous words themselves. In the CAP paradigm, ambiguous words are presented in a visual or auditory context consisting of a word, clause, or sentence that contains neutral, semantically biasing, or syntactically biasing information. The ambiguous words are then followed (sometimes at various stimulus onset asynchronies) by a target word that is either related to the contextually appropriate or contextually inappropriate reading of the critical word or is unrelated to either; subjects are usually required to perform some task on the target words (for example, word naming, lexical decision, or letter search). The results for within-word-class semantically ambiguous words (e.g., ‘spade’, ‘bank’) have been variable across paradigms and measurements. While many behavioral studies suggest that multiple meanings of ambiguous words are accessed regardless of prior context (Seidenberg et al., 1982; Tanenhaus and Donnenwerth-Norlan, 1984; Tanenhaus et al., 1979), a few studies have suggested that, with a sufficient level of bias, context information can restrict meaning access (e.g., Simpson and Krueger, 1991). Still, other research emphasizes the interaction between meaning dominance and contextual preference (Pacht and Rayner, 1993, eye movement study).

Almost all studies that have looked at words that are word class ambiguous have used those that have different meanings across their noun and verb senses (e.g., ‘duck’, ‘rose’). Results from the CAP paradigm have favored the multiple access view for these items, even in syntactically well-specified contexts (Seidenberg et al., 1982; Tanenhaus and Donnenwerth-Norlan, 1984; Tanenhaus et al., 1979; Van Petten, 2002). However, mixed results have been obtained for measures on the ambiguous words themselves. For example, Van Petten and Kutas (1987) found no significant ERP differences when they directly compared the processing of unambiguous and ambiguous (both within-word-class and across-word-class) words. A recent eye movement study also reported that syntactic context information can constrain access to the structurally appropriate meaning: relative to fixation times for lexically unambiguous words, fixation times were longer for within-class (noun–noun) semantically ambiguous words but *not* for across-class (noun–verb) semantically ambiguous words (Folk and Morris, 2003). These findings stand in contrast to those of Federmeier et al. (2000), who found ambiguity effects even when the preceding context prescribed the appropriate use, and hence meaning, of the word and when the experimental task required only one meaning to be activated.

In summary, there remain many open questions about the processing consequences of – and interactions between – word class and semantic ambiguity. Moreover, little research on the resolution of ambiguity with syntactically explicit contextual information has been conducted with ERPs. Therefore, the current study was designed to replicate and extend the work of Federmeier et al. (2000), using ERPs to investigate the processing of nouns, verbs, and word class ambiguous items in syntactically well-defined contexts. Here, word class ambiguous words were divided into two categories: those whose noun and verb meanings were semantically distinct (“semantically ambiguous”—as determined by ratings of subjective similarity) and those whose meanings were much more similar (“semantically unambiguous”). Instead of a sentence-reading task, we employed a priming paradigm in which ambiguous and unambiguous items were preceded by a noun-predicting (“the”) or a verb-predicting (“to”) cue. By using minimal phrases instead of sentences, we could retain the core syntactic cue information while presenting more items within a single session. Ambiguous items were used with both cue types; unambiguous items were paired with the syntactically appropriate cue so that all stimulus conditions were grammatically legal.

We expect to replicate the word class differences observed by Federmeier et al. (2000), with enhanced N400 responses to nouns and increased frontal positivity to unambiguous verbs. Moreover, by separately manipulating word class ambiguity and semantic ambiguity, we hope to clarify the nature of the slow, frontal ambiguity effect. If this effect is due to word class ambiguity as such, then it should appear irrespective of the level of semantic similarity between the noun and verb senses of the word. It is also possible, however, that word class ambiguity only impacts processing when the noun and verb senses of the word are semantically distinct. In this case, we should see the frontal negativity primarily or exclusively for items with both word class and semantic ambiguity. Similarly, the lack of a frontal positivity to ambiguous verbs could be due to their status as class ambiguous items or could reflect difficulties with meaning selection that should primarily apply to items with greater semantic ambiguity.

2. Results

2.1. Behavior

On average, participants correctly responded to 95% (range 88–99%) of the probe semantic-relatedness questions. Thus, participants seemed to be processing the experimental stimuli for meaning and appropriately using the syntactic cues to access the noun or verb senses of ambiguous words.

2.2. ERPs

Effects of ambiguity and word class were assessed via comparisons of mean amplitude in the time windows of interest, based on the findings of Federmeier et al. (2000) and visual inspection of the data. For each analysis of variance (ANOVA), the Huynh–Feldt adjustment to the degrees of freedom was applied to correct for violations of sphericity associated with repeated measures. Accordingly, for all *F* tests with more than 1 degree of freedom in the numerator, the corrected *P* value is reported.

2.3. Ambiguity

Fig. 1 shows the responses, at 8 representative electrode sites, to the AA, AU, and UW conditions, collapsed across noun/verb status. Federmeier et al. (2000) observed greater frontal negativity to word class ambiguous words, as compared with their unambiguous counterparts, beginning in the P2 time window (150 to 250 ms) and continuing from 250 to 500 and 500 to 900 ms. Here, we observe a similar difference between the AA and UW conditions from approximately 250 ms to the end of the epoch; this effect is widely distributed over the frontal and central electrode sites but appears to be more prominent in the frontal area. Responses to the AU condition, in contrast, appear more positive than those to the UW condition in some parts of the epoch. An analysis of variance (ANOVA) with three levels of ambiguity (AA/AU/UW) and 11 levels of electrode (frontal sites) revealed no effect of ambiguity in the earliest time window (150–250) [$F < 1$], but a main effect in both the 250–500 ms time window [$F(2,50) = 14.30$; $P < 0.01$] and the 500–900 ms time window [$F(2,50) = 3.78$; $P = 0.03$]. Planned comparisons revealed that items with both word class and semantic ambiguity were more negative than unambiguous items between 250 and 500 ms (mean amplitude AA = 0.11 μV, mean amplitude UW = 0.86 μV, [$F(1,25) = 8.18$; $P < 0.01$]), and this effect continued to be marginally significant between 500 and 900 ms [$P = 0.06$]. This effect becomes significant in this time window as well if a slightly larger subset of electrodes, including those over central sites, are used (mean amplitude AA = 1.55 μV, mean amplitude UW = 2.07 μV, [$F(1,25) = 5.02$; $P = 0.03$]). Items with only word class ambiguity were more positive than unambiguous items between 250 and 500 ms (mean amplitude AU = 1.45 μV, [$F(1,25) = 8.94$; $P < 0.01$]); these conditions did not differ in the later time window. AA and AU items also differed from one another in both time windows (250–500 ms [$F(1,25) = 22.67$; $P < 0.01$]; 500–900 ms (mean amplitude AA = 1.98 μV, AU = 2.65 μV, [$F(1,25) = 5.07$; $P = 0.03$]).

In summary, beginning around 250 ms, a slow frontal negativity was observed for AA words relative to their unambiguous counterparts. AU words, instead, elicited greater positivity than unambiguous words, in a more restricted time window.

2.4. Word class (noun versus verb)

Following Federmeier et al. (2000), comparisons of the brain responses to nouns and verbs were conducted over central and posterior electrode sites in the N400 time window (250–450 ms) and over frontal sites between 300 and 700 ms (verb-related positivity).

2.4.1. Central/posterior sites (N400)—Fig. 2 shows the response to nouns and verbs collapsed across ambiguity condition. In the Federmeier et al. (2000) study, word class affected the amplitude of the N400 (250 to 450 ms, central–posterior sites), with larger responses to nouns than to verbs, independent of ambiguity. A similar effect seems to hold in the current study.

An ANOVA with three levels of ambiguity (AA/AU/UW), two levels of word class (noun/verb), and 15 levels of electrodes (15 central/posterior electrodes) indicated a main effect of ambiguity [$F(2,50) = 9.58$; $P < 0.001$], which interacted with electrode [$F(28,700) = 4.43$; $P < 0.01$]. Follow up comparisons revealed a significant main effect of ambiguity over all but the four most lateral electrode sites; this pattern reflects a continuation over central electrode sites of the ambiguity effect already described over frontal sites. The main effect of word class was not significant, but there was a word class by electrode interaction [$F(14,350) = 3.61$; $P < 0.01$]. Follow up comparisons indicated a main effect of word class over a subset of 11 channels (dropping lateral sites, where N400 effects tend to be small) when a slightly narrower time window (250–400 ms), more focused on the peak of the effect, was considered [$F(1,25) = 4.9$; $P < 0.05$]. Ambiguity did not interact with word class.

2.4.2. Frontal sites (verb-related positivity)—Replicating findings of enhanced frontal positivity (of variable latency) to verbs, Federmeier et al. (2000) reported a frontal positivity between 200 and 400 ms that was selectively enhanced for unambiguous verbs, compared to all other conditions. A similar effect was visually apparent in this study, but the positivity seemed to begin later and last longer than that in Federmeier et al. (2000).

Fig. 3 shows the response to nouns and verbs for word class unambiguous words (right) and word class ambiguous words (left). There is a frontal positivity, beginning around 300 ms, to UV items relative to UN items. Note that this effect seems to be absent in the comparison between class ambiguous nouns and class ambiguous verbs.

Planned comparisons (conducted over frontal electrode sites) revealed greater positivity to unambiguous verbs (1.30 μV) than to unambiguous nouns (0.72 μV) between 300 and 700 ms [$F(1,25) = 4.47$; $P < 0.05$]. However, this difference was not observed for ambiguous items, either when collapsed across semantic ambiguity or when AA and AU are considered separately.

In summary, nouns were associated with a spatially restricted enhancement of the N400 relative to verbs. Replicating Federmeier et al. (2000), verbs elicited a frontal positivity between 300 and 700 ms—but only when word class unambiguous.

3. Discussion

The purpose of the current study was to replicate the word class effects reported in Federmeier et al. (2000) and to extend those findings by determining whether – and, if so, how – effects attributed to word class ambiguity might be modulated by semantic ambiguity across a word's noun and verb senses. Federmeier et al. (2000) found an enhanced central–posterior negativity (N400) for nouns in comparison with verbs and a left frontal positivity that was specific to unambiguous verbs. In addition, a slow frontal negativity was observed for class ambiguous words, irrespective of whether these were used as nouns or verbs in a sentence context; it is this effect in particular that we hypothesized might be influenced by semantic ambiguity. To examine this, four types of words were used in the current experiment: (1) word class ambiguous words with a high degree of semantic ambiguity; (2) word class ambiguous words with little or no semantic ambiguity; (3) word class unambiguous nouns; and (4) word class unambiguous verbs. These words were preceded by cues that explicitly established an expectation for the word class of the targets; nouns (and ambiguous words used as nouns) were preceded by the word "the" and verbs (and ambiguous words used as verbs) were preceded by the word "to". Brain responses elicited by unambiguous nouns and verbs and ambiguous items used as nouns and verbs were compared in order to examine effects of word class and their interactions with context, and the ERPs associated with the three different types of words (unambiguous, syntactically ambiguous only, and syntactically and semantically ambiguous) were compared in order to clarify the nature of the slow frontal negativity.

We replicated the word class effects observed by Federmeier et al. (2000), finding larger N400 responses to nouns than to verbs irrespective of ambiguity and enhanced frontal positivity to unambiguous verbs as compared with unambiguous nouns. Critically, we also dissociated the ambiguity effect, finding enhanced frontal negativity only to those class ambiguous words that also had a high degree of semantic ambiguity. We discuss these effects in turn, beginning with the replications and then progressing to the ambiguity effect that was of central interest for the present study.

Using minimal phrases (instead of whole sentences), the current study successfully replicated the word class effects reported in Federmeier et al. (2000). First, over central–posterior scalp sites, therewas an enhanced N400 (250–450 ms) for nouns compared with verbs. This was a main effect of word class, which did not interact with the presence of word class ambiguity or semantic ambiguity. This result is consistent with findings from studies of aphasia that report selective deficits for words from different grammatical categories that are independent of both noun/verb homophony and the relatedness of noun meanings and verb meanings (Caramazza and Hillis, 1991; Goldberg and Goldfarb, 2005; Jonkers and Bastiaanse, 1998;Kemmerer and Tranel, 2000). However, not all studies have found this kind of N400 difference between nouns and verbs. Gomes et al. (1997), for example, did not find any significant amplitude or distributional difference in the N400 elicited by nouns and verbs when comparing noun–noun and noun–verb pairs in a semantic priming paradigm. Similarly, although we did not perform direct comparisons of the two effects, the noun–verb N400 difference in the current data appears smaller than that in Federmeier et al. (2000). Thus, this particular word class effect seems to vary with the context in which the words are embedded and/or the particular items that are used. In this study, we controlled for basic lexical properties (frequency, length) of the words in the two classes but not for all higher-level characteristics that might affect N400 amplitude, such as concreteness, lexical neighborhood density, number of arguments, or degree of polysemy. Therefore, it remains unclear if this is a word class effect as such or reflects other factors that tend to covary with word class (and, indeed, may constitute part of what “word class” means and/or how the brain identifies different classes of words).

Second, as was seen in Federmeier et al. (2000), there was a frontal positivity to verbs: unambiguous verbs (in relation to unambiguous nouns) elicited enhanced positivity over prefrontal and frontal sites (with a slight left-bias) from 300 to 700 ms post-stimulus-onset. Consistent with what was found in Federmeier et al. (2000), this frontal positivity was only observed for class unambiguous verbs in comparison with class unambiguous nouns, but not in the noun/verb comparison of the other two pairs of class ambiguous words. The frontal positivity for class unambiguous verbs in the current study emerged slightly later than that in Federmeier et al. (who measured it between 200 and 400 ms). One possible explanation for the different latencies is the different paradigms used in the two experiments. Since target words were embedded in sentences in Federmeier et al. (2000), participants may have benefited from the preceding context and therefore processed the target words more quickly (Morris, 1994; Pierce and Beekman, 1985; Swinney and Hakes, 1976). Furthermore, it is possible that the need to parse a sentence tends to speed the analysis of word class.

Although the scalp topography of an ERP effect cannot be used to make direct inferences about the localization of brain sources, data from other methods have suggested a link between the processing of verbs and activity in left frontal areas of the brain. Some studies suggest that this effect reflects semantic aspects of the stimuli (e.g., motor vs. visual associations) rather than a distinction between grammatical categories as such (noun vs. verb) (Pulvermuller, 2001; Pulvermuller et al., 1999b), while others have related left frontal areas to specific grammatical features of verbs (for example, verb-specific suffixes or argument complexity) and suggested that left frontal regions (Perani et al., 1999 have specifically pointed to Broca’s area) may contain a ‘verb-specific’ area (Cappa and Perani, 2003; Collina et al., 2001; Perani et al., 1999). However, that this distinction only shows up for the class unambiguous verbs in the present study suggests that this area may be associated with specific information or processing that does not apply to all words used as verbs. This is consonant with the results of a PET study using a picture confrontation-naming paradigm, in which word class unambiguous action verbs were found to activate some extra areas (the left frontal operculum as well as a left posterior middle temporal area) as compared with word class ambiguous verbs and both word class ambiguous and unambiguous nouns (Tranel et al., 2005). In view of this, an important future direction for the field will be to narrow down the possible factors – lexical, semantic, syntactic or others – that set word class unambiguous verbs apart from their ambiguous counterparts. Given that the effect is not seen to these same lexical items when inappropriately embedded in a noun-predicting context (Federmeier et al., 2000), it is also important to study how this factor interacts with context.

Having shown that the basic effects of word class were replicated within the current paradigm, the key goal of the study was to clarify the nature of the slow frontal effect observed in Federmeier et al. (2000). To that end, brain responses were compared across the three word types: class ambiguous words with a high degree of semantic ambiguity (AA), class ambiguous words with little (or no) semantic ambiguity (AU), and class unambiguous words (UW). The data showed enhanced frontal negativity from around 250 ms to 900 ms post-stimulus-onset, but only for words with *both* semantic and word class ambiguity (AA), as compared with either class unambiguous words or class ambiguous words with little semantic ambiguity (AU). Indeed, AU words actually elicited more positivity than class unambiguous words in the early part of this time window (250–500 ms). Thus, the frontal negativity observed by Federmeier et al. (2000) is clearly not a general effect of word class ambiguity.

The graded pattern (in the earlier part of the time window) is quite striking, with the class unambiguous items falling in between the two kinds of class ambiguous items. One possibility for this graded pattern is a graded level of semantic ambiguity in the three conditions. The experiment was designed so that AA items have a high level of semantic ambiguity across their noun and verb senses while AU items have a low level of semantic ambiguity. We did not specifically control for (within-class) semantic ambiguity among the class unambiguous items. An examination of our stimuli suggests that there was little overt ambiguity, but it is possible that these items were more polysemous than the AU words. If so, the graded pattern observed might reflect the difficulty of semantic selection engendered by the different classes of items.

Alternatively, the graded pattern might reflect influences of a lexico-semantic difference between the conditions that covaried with our ambiguity manipulation. Although we carefully controlled our items for lexical properties such as length and class-specific word frequency, we did not control for all higher-level properties of the words (indeed, such control may not be possible). Concreteness, in particular, has been associated with effects that are in some ways similar to the pattern we observe in the present study, with more concrete words eliciting greater negativity (extending over frontal electrode sites) in the N400 time window (250–500 ms) and beyond (Kounios and Holcomb, 1994; Holcomb et al., 1999; West and Holcomb, 2000). This effect is most evident in imagery tasks and therefore has been interpreted as reflecting activation in a mental imagery subsystem, an information lookup system, or in working memory (West and Holcomb, 2000). In the present study, the average concreteness of the AA condition was higher than that of the other two classes of words (for those items for which concreteness ratings were available[1]). To test how important this concreteness difference might have been for our effect pattern, we did a post hoc subdivision (median split on concreteness) within each of the

[1]Concreteness ratings were not available for the majority of the word class unambiguous verbs. Furthermore, standard concreteness ratings in the MRC Psycholinguistic Database (Wilson 1987) have not taken either word class or semantic ambiguity into account; it is therefore difficult to know whether the rating for a particular ambiguous word reflects judgments about one of its senses (and, if so, which one) or a mix of both. In order to better examine the possible influence of concrete on the current pattern of effects, therefore, our post hoc analyses were done using a subset of the ambiguous words for which we had obtained separate concreteness ratings for the noun and verb senses (as part of another ongoing study).

conditions for which we had concreteness ratings for most of the words (AA, AU, and UN) and compared at the same 11 frontal electrode sites. This post hoc analysis revealed that concreteness does indeed modulate the effect pattern but cannot explain it completely. Effects of concreteness were not uniform: differences were seen for the AA and UN words, but not for the AU ones (though the average concreteness difference between the low and high halves was actually greatest for this condition). These effects, when present, were limited to the early time window[2]. Most importantly, it is clear that concreteness cannot explain the whole pattern because a significant effect of semantic ambiguity could still be seen when a concreteness-matched subset (34 for AA and 64 for AU) of AA and AU items was compared [250–500 ms $F(1,25) = 8.76$; $P < 0.01$; 500–900 ms $F(1,25) = 5.13$; $P < 0.05$]. It is interesting to note that prior studies reporting ERP effects of concreteness did not control for word class or ambiguity and that at least some of the concrete words used in those studies (the full set of items was not reported) were actually both word class and semantically ambiguous (e.g., 'rose' in Holcomb et al., 1999). Thus, it is possible that the effect in those studies might have reflected the joint influence of concreteness and ambiguity; more work will be needed to disentangle these factors.

Over and above a possible concreteness effect, then, we observed a frontal negativity to those class ambiguous words that also had a high degree of semantic ambiguity across their noun and verb senses—suggesting that this effect may reflect processing difficulties associated with the resolution of meaning ambiguity rather than with class ambiguity per se. The actual word class and, therefore, meaning of semantically ambiguous items could in principle be completely determined by the presence of the syntactic cue. Nevertheless, the data pattern obtained in this study (and in Federmeier et al. (2000)) show that this information was not sufficient to completely resolve the ambiguity and suggest that both the noun and verb meanings of the AA words may have been at least partially activated, possibly entailing greater selection demands.

The literature contains other reports of cases in which there seems to be multiple access of meanings for word class and semantically ambiguous words that are embedded in syntactically well-specified contexts. Tanenhaus et al. (1979), using the cross-modal CAP paradigm, found that, when target words were presented at a short delay after the onset of a noun–verb semantically ambiguous word (<200 ms), naming latencies to targets associated with both the noun and the verb reading of the ambiguous word were facilitated. After 200 ms, however, only the targets that were associated with the context-appropriate reading were facilitated. The authors suggest that this might result from an active suppression of the context-inappropriate meanings. Seidenberg et al. (1982), successfully replicating the findings of Tanenhaus et al. (1979) with the same paradigm, found no contextual effects for both noun–noun semantically ambiguous words and noun–verb semantically ambiguous words with a 0 ms SOAs between the ambiguous word and the target; multiple readings were accessed even when the preceding context was semantically biasing or syntactically unambiguous. By 200 ms SOAs, only the context appropriate readings were accessed for all word types. In still another study using the CAP paradigm, Tanenhaus and Donnenwerth-Norlan (1984) embedded noun–verb semantically ambiguous words in even more restrictive syntactic contexts and still found similar facilitation effects for targets related to both syntactically correct and syntactically incorrect meanings. These studies thus seem to consistently support the idea that multiple readings are accessed (possibly automatically) for ambiguous items, even when the context specifies their part of speech and/or something about their meaning (Seidenberg et al., 1982; Tanenhaus and Donnenwerth-Norlan, 1984; Tanenhaus et al., 1979). A recent eye movement study (Folk and Morris, 2003), using a leading context that unambiguously specified syntactic category, found that fixation times were longer for noun–noun semantically ambiguous words than for lexically unambiguous items but were not lengthened for noun–verb semantically

[2]250–500 ms: AA [$F(1,25) = 6.45$; $P < 0.05$], UW [$F(1,25) = 8.76$; $P < 0.01$], AU [$F(1,25) = 0.06$; $P = 0.80$]; 500–900 ms: AA [$F(1,25) = 1.35$; $P = 0.26$], UW [$F(1,25) = 1.99$; $P = 0.17$], AU [$F(1,25) = 2.38$; $P = 0.28$].

ambiguous words. Folk and Morris explained this pattern by suggesting that, while all the meanings of ambiguous words are initially activated, either (1) syntactic information in a context can reorder the priority of meanings, such that the syntactically appropriate interpretation is accessed and integrated first, or (2) the process of syntactic category assignment precedes semantic resolution, such that after the syntactic category is assigned there is no further semantic ambiguity.

The current finding thus seems consistent with the multiple access view (Seidenberg et al., 1982; Tanenhaus and Donnenwerth-Norlan, 1984; Tanenhaus et al., 1979) and/or the ordered activation view (Folk and Morris, 2003). The claims of the multiple access view have been weakened by the argument that facilitation for contextually inappropriate readings at short SOAs might result from backward priming from the following targets (Burgess et al., 1989). However, in the current study, only one-third of the trials were followed by a probe for semantic relatedness, and these were presented 1500 ms after the offset of the ambiguous words—well beyond the ERP measurement epoch. Thus, the ERP results suggest relatively early and relatively long-lasting effects of ambiguity for items that differ in meaning across a noun and verb sense; this is true even in contexts that in principle provide sufficient syntactic information to resolve that ambiguity. However, the current design does not allow for an examination of the time course or strength of activation for the different senses of the ambiguous word (Van Petten and Kutas, 1987, 1990, 1991).

The ambiguity effects observed in the present study occurred for priming in word pairs (cue–target). To examine the generalizability of these effects to sentence processing, a reanalysis of the original data from Federmeier et al. (2000) was conducted in which the class ambiguous items were split by semantic ambiguity. Although the original control for word frequency and word length no longer holds after the division of class ambiguous words into a subset with high levels of semantic ambiguity ($N = 60$; semantic similarity rating <5.1 [mean 3.70, range 1.35–5.08]) and a subset with less semantic ambiguity ($N = 60$; semantic similarity rating <5.1 [mean 5.49, range 5.15–5.92]), the pattern of results is highly similar to that observed in the current study. Post hoc analysis shows that AA words are more negative than UW between 250 and 500 ms (mean amplitude AA = 0.59 μV, AU = 1.67 μV, [$F(1,21) = 14.81$; $P < 0.01$]). Thus, in the data of Federmeier et al. (2000), as in the present study, the frontal negativity in this time window seems to be more driven by semantic than by word class ambiguity as such. However, it is worth noting that the ambiguity effect reported by Federmeier et al. had an extended time course, beginning in the time frame of the P2 component (150–250 ms) and continuing into the next word. The semantic ambiguity effects brought out by the post hoc analysis were more restricted in their time course (and similar in time course to the effects in the present study), with some parts of the epoch (especially later in time) seeming to manifest more general influences of class ambiguity. Thus, there may be multiple, temporally and functionally distinguishable effects reflected in the frontal negativity originally reported by Federmeier et al. (2000). Of most importance for the present study is that the effects in the middle part of the epoch (250–500 ms) were most apparent for items that are semantically, as well as word class, ambiguous.

In summary, the current experiment confirmed the word class effects reported in a prior study (Federmeier et al., 2000): nouns are associated with larger negativity than verbs over central–parietal scalp sites, and verbs, particularly word class unambiguous ones, are characterized by larger positivity over frontal electrodes. Crucially, the present data provide new evidence suggesting that at least part of the word class ambiguity effect reported by Federmeier et al. is driven by the need to resolve the semantic ambiguity that sometimes – though not always – is associated with the different grammatical uses of these words. This, in turn, highlights the importance of investigating the interconnection between semantic and syntactic information in language processing. The present study also reinforces the idea that words, and classes of words, differ along multiple dimensions and that these will interact in determining how easy or difficult the processing of a particular word will be and what cognitive and neural resources must be brought to bear.

4. Experimental procedures

4.1. Materials

Stimulus materials consisted of 64 of each of four word types: (1) words with word class ambiguity (can be used as both nouns and verbs) as well as a high degree of semantic ambiguity (noun and verb senses have very different meanings, as determined by norming (described below); e.g., *the duck/to* duck), henceforth AA (syntactically Ambiguous–semantically Ambiguous); (2) words with word class ambiguity but little or no semantic ambiguity (e.g., *the vote/to vote*), henceforth AU (syntactically Ambiguous–semantically Unambiguous); (3) nouns with no word class ambiguity (e.g., *the sofa*), henceforth UN (syntactically Unambiguous Nouns); and (4) verbs with no word class ambiguity (e.g., *to eat*), henceforth UV (syntactically Unambiguous Verbs). Appendix A shows examples of each of the stimulus types. Two syntactic cues were used: the noun-predicting cue 'the' and the verb-predicting cue 'to'. Each of the words from the AA and AU conditions was used once after 'the' and once after 'to'. Words were split into two lists so that individual participants saw each word only once. Each participant read 256 'phrases' in total. Word length and word frequency (Kucera and Francis, 1967) were matched across conditions and within lists. Word class ambiguous items were matched for their average frequency of use as nouns and verbs. Trials were randomized within each list and presented to each participant in the same order.

4.2. Rating for semantic ambiguity

The degree of perceived semantic ambiguity across the noun and verb senses of word class ambiguous words was determined using a paper and pencil norming study. 26 UIUC undergraduate students (17 men and 9 women, mean age 19, range 18–21) participated in the norming session for course credit; all were monolingual speakers of English. Participants were asked to use a 7-point scale to rate 433 syntactically ambiguous words for the similarity between their meanings when used as a noun versus when used as a verb. Arating of "1" was used to indicate that the meanings are "very different" and a rating of "7" was used to indicate that the meanings are "very similar". 64 semantically unambiguous words (ambiguity rating >3.5; mean 5.49, range 5.00–6.00) and 64 semantically ambiguous words (ambiguity rating <3.5; mean 2.27, range 1.15–3.28) were selected from the rated set.

Of central importance for the current study was the similarity or distinctiveness of the information most readily brought to mind by the words in their dominant noun and verb usages. Thus, the classification of items into semantically unambiguous and ambiguous categories was done using the ratings and not according to linguistically based distinctions between homonymy and polysemy. Some words with noun and verb senses that may be historically related (e.g., *swamp*) were regarded by the participants in the norming study to be "very different" in meaning and were therefore classified as semantically ambiguous. Furthermore, we avoided, where possible, but did not specifically control for, additional polysemy within the noun or verb usage of the word.

4.3. Participants

Twenty-six undergraduate students (13 men and 13 women, mean age 20, range 18–23) at the University of Illinois at Urbana-Champaign participated in this study for cash or course credit. All participants were right-handed as assessed by the Edinburgh inventory (Oldfield, 1971); 12 reported having left-handed or ambidextrous family members. No subject had a history of neurological/psychiatric disorders, and all were monolingual speakers of English with no consistent exposure to other languages before age 5. Participants were randomly assigned to one of the two lists.

4.4. Procedure

Participants were seated 100 cm in front of a 21 in. computer monitor in a dim, quiet testing room. The experiment began with an 18-trial practice session to familiarize subjects with the task and the experimental environment. At the start of each trial, a series of plus signs appeared in the center of the computer screen for 500 ms. After an SOA ranging randomly between 1000 and 1500 ms, the cue ("to"/"the") and the target word were presented one by one, each for 200mswith a 500ms SOA. A probe for a semantic-relatedness judgment (described below) followed one-third of the target words and a capitalized message 'NEXT TRIAL' followed the other two-thirds of the targets. In both cases, the phrase was displayed all at once on the screen in red color 1500 ms after the offset of the target and remained on the screen until the participant's response. The next trial then began after a delay of 2500 ms.

A semantic-relatedness judgment task was used to ensure that participants attended to the stimuli and processed them for meaning (as would be expected during normal comprehension). Participants were told that a probe phrase would appear (unpredictably) after a subset of the trials. Their task was to decide whether the phrase was semantically related or unrelated to the test trial that had immediately preceded it and to indicate their judgment with a button press; hand used to respond "yes" and "no" was counterbalanced across participants. Half of the probe trials were semantically related, consisting of either a synonym or definition of the target word in the sense specified by the syntactic cue (e.g., the target phrase 'the income' with the probe phrase 'the earnings') and half were unrelated to any sense of the word (e.g., the target phrase 'the salad' with the probe phrase 'the article'). Probes always contained the same syntactic cue ("the" or "to") as that used in the immediately preceding trial. The probe phrases therefore did not draw special attention to either the word class or the potential ambiguity of the words. For the non-probe case, subjects would initiate the next trial by pressing either button.

4.5. EEG recording parameters

The electroencephalogram (EEG) was recorded from twenty-six geodesically arranged silver/silver-chloride electrodes attached to an elastic cap. The twenty-six electrodes are midline prefrontal (MiPf), left and right medial prefrontal (LMPf and RMPf), left and right lateral prefrontal (LLPf and RLPf), left and right medial frontal (LMFr and RMFr), left and right mediolateral frontal (LDFr and RDFr), left and right lateral frontal (LLFr and RLFr), midline central (MiCe), left and right medial central (LMCe and RMCe), left and right mediolateral central (LDCe and RDCe), midline parietal (MiPa), left and right mediolateral parietal (LDPa and RDPa), left and right lateral temporal (LLTe and RLTe), midline occipital (MiOc), left and right medial occipital (LMOc and RMOc), and left and right lateral occipital (LLOc and RLOc). All scalp electrodes were referenced on-line to the left mastoid and re-referenced offline to the average of the right and the left mastoids. In addition, one electrode was placed on the left infraorbital ridge to monitor the vertical EOG, and another two electrodes were placed on the outer canthus of each eye to monitor the horizontal EOG. Electrode impedances were kept below 3 kΩ. The continuous EEG was amplified through a bandpass filter of 0.02–100 Hz and recorded at a sampling rate of 250 Hz. EEG data were stored on a hard disk for later analyses.

4.6. Data analysis

ERPs were computed from 100 ms before the onset of critical words to 920 ms after. Epochs containing artifacts from amplifier blocking, signal drift, excessive eye movements, or muscle activity were rejected off-line before averaging, and those contaminated by eye blinks were corrected (Dale, 1994). On average, 6% of trials were lost due to such artifacts. Data were re-

referenced to the algebraic mean of the left and right mastoids, and averages of artifact-free ERPs were calculated for each type of target word (AA, AU, UN, UV) in each type of phrase (noun-predicting and verb-predicting) after subtraction of the 100 ms pre-stimulus baseline. Prior to measurement, ERPs were digitally filtered with a bandpass of 0.2–20 Hz.

Acknowledgments

The authors would like to thank Susan Garnsey, Gary Dell, Kay Bock, Aaron Benjamin, and Aaron Meyer for insightful comments on an earlier version of this article. The authors would also like to thank Yoko Ieuji and Caterina Gratton for the help with data collection.

Appendix

Appendix

Appendix A

Stimulus materials

AA	AU	UN	UV
Bar	Answer	Bonus	Accept
Bear	Damage	Chaos	Admit
Crush	Dance	City	Appear
Duck	Drink	Coffee	Argue
Floor	Echo	Danger	Bake
Mind	Fear	Debt	Become
Mug	Fight	Driver	Chew
Page	Guess	Duty	Come
Park	Hint	Error	Decide
Rock	Joke	Irony	Differ
Season	Laugh	Logic	Eat
Sentence	Lecture	Mixture	Explain
Spell	Party	Moment	Gather
Stand	Pause	Music	Grow
Stick	Plan	Region	Ignore
Swallow	Promise	Salad	Justify
Tire	Risk	Skill	Marry
Track	Search	Sofa	Operate
Trip	Sleep	Talent	Relax
Watch	Vote	Truth	Sit

REFERENCES

Berndt RS, Zingeser LB. Grammatical class effects in word production: finding the locus of the deficit. Brain Lang 1991;41:597–600. [PubMed: 1723334]

Brown WS, Marsh JT, Smith JC. Contextual meaning effects on speech-evoked potentials. Behav. Biol 1973;9:755–761. [PubMed: 4764256]

Brown WS, Marsh JT, Smith JC. Evoked potential waveform differences produced by the perception of different meanings of an ambiguous phrase. Electroencephalogr. Clin. Neurophysiol 1976;41:113–123. [PubMed: 58774]

Brown WS, Lehmann D, Marsh JT. Linguistic meaning related differences in evoked potential topography English, Swiss–German, and imagined. Brain Lang 1980;11:340–353. [PubMed: 7470853]

Brown CM, Hagoort P, Keurs Mt. Electrophysiological signatures of visual lexical processing: open- and closed-class words. J. Cogn. Neurosci 1999;11:261–281. [PubMed: 10402255]

Burgess C, Tanenhaus MK, Seidenberg MS. Context and lexical access: implications of nonword interference for lexical ambiguity resolution. J. Exper. Psychol., Learn., Mem., Cogn 1989;15:620–632. [PubMed: 2526855]

Cairns HS, Kamerman J. Lexical information processing during sentence comprehension. J. Verbal Learn. Verbal Behav 1975;14:170–179.

Cappa SF, Perani D. The neural correlates of noun and verb processing. J. Neurolinguist 2003;16:183–189.

Caramazza A, Hillis AE. Lexical organization of nouns and verbs in the brain. Nature 1991;349:788–790. [PubMed: 2000148]

Collina S, Marangolo P, Tabossi P. The role of argument structure in the production of nouns and verbs. Neuropsychologia 2001;39:1125–1137. [PubMed: 11527549]

Dale, AM. Source Localization and Spatial Discriminant Analysis of Event-related Potentials: Linear Approaches. La Jolla, CA: University of California San Diego; 1994.

Daniele A, Giustolisi L, Silveri MC, Colosimo C, Gainotti G. Evidence for a possible neuroanatomical basis for lexical processing of nouns and verbs. Neuropsychologia 1994;32:1325–1341. [PubMed: 7533275]

Dehaene S. Electrophysiological evidence for category-specific word processing in the normal human brain. NeuroReport 1995;6:2153–2157. [PubMed: 8595192]

Federmeier KD, Segal JB, Lombrozo T, Kutas M. Brain responses to nouns, verbs and class-ambiguous words in context. Brain 2000;123(12):2552–2566. [PubMed: 11099456]

Folk JR, Morris RK. Effects of syntactic category assignment on lexical ambiguity resolution in reading: an eye movement analysis. Mem. Cogn 2003;31:87–99.

Gentner D. Some interesting differences between verbs and nouns. Cogn. Brain Theory 1981;4:161–178.

Gentner, D. Why nouns are learned before verbs: linguistic relativity versus natural partitioning. In: Kuczaj, SA., editor. Language Development. Language, Thought and Culture. Vol. vol. 2. Hillsdale, NJ: Erlbaum; 1982. p. 301-334.

Goldberg E, Goldfarb R. Grammatical category ambiguity in aphasia. Brain Lang 2005;95:293–303. [PubMed: 16246737]

Gomes H, Ritter W, Tartter VC, Vaughan HG Jr, Rosen JJ. Lexical processing of visually and auditorily presented nouns and verbs: evidence from reaction time and N400 priming data. Cogn. Brain Res 1997;6:121–134.

Hino Y, Lupker SJ, Pexman PM. Ambiguity and synonymy effects in lexical decision, naming, and semantic categorization tasks: interactions between orthography, phonology, and semantics. J. Exper. Psychol., Learn., Mem., Cogn 2002;28:686–713. [PubMed: 12109762]

Holcomb PJ, Kounios J, Anderson JE, West WC. Dual coding, context-availability, and concreteness effects in sentence comprehension: an electrophysiological investigation. J. Exper. Psychol., Learn., Mem., Cogn 1999;25:721–742. [PubMed: 10368929]

Jastrzembski JE. Multiple meanings, number of related meanings, frequency of occurrence, and the lexicon. Cogn. Psychol 1981;13:278–305.

Jastrzembski JE, Stanners RF. Multiple word meanings and lexical search speed. J. Verbal Learn. Verbal Behav 1975;14:534–537.

Jonkers R, Bastiaanse R. How selective are selective word class deficits? Two case studies of action and object naming. Aphasiology 1998;12:245–256.

Kellas G, Ferraro FR, Simpson GB. Lexical ambiguity and the timecourse of attentional allocation in word recognition. J. Exp. Psychol. Hum. Percept. Perform 1988;14:601–609. [PubMed: 2974871]

Kemmerer D, Tranel D. Verb retrieval in brain-damaged subjects: 1. Analysis of stimulus, lexical, and conceptual factors. Brain Lang 2000;73:347–392. [PubMed: 10860561]

Kounios J, Holcomb PJ. Concreteness effects in semantic processing: ERP evidence supporting dual-coding theory. J. Exper. Psychol., Learn., Mem., Cogn 1994;20:804–823. [PubMed: 8064248]

Kucera; Francis, WN. Computational Analysis of Present-day American English. Providence: Brown Univ. Press; 1967.

Li P, Jin Z, Tan LH. Neural representations of nouns and verbs in Chinese: an fMRI study. NeuroImage 2004;21:1533–1541. [PubMed: 15050577]

McCarthy R, Warrington EK. Category specificity in an agrammatic patient: the relative impairment of verb retrieval and comprehension. Neuropsychologia 1985;23:709–727. [PubMed: 4080135]

Miceli G, Silveri MC, Villa G, Caramazza A. On the basis for the agrammatic's difficulty in producing main verbs. Cortex 1984;20:207–220. [PubMed: 6204813]

Miceli G, Silveri MC, Nocentini U, Caramazza A. Patterns of dissociations in comprehension and production of nouns and verbs. Aphasiology 1988;2:351–358.

Morris RK. Lexical and message-level sentence context effects on fixation times in reading. J. Exper. Psychol., Learn., Mem., Cogn 1994;20:92–103. [PubMed: 8138791]

Myerson R, Goodglass H. Transformational grammars of three agrammatic patients. Lang. Speech 1972;15:40–50. [PubMed: 5073934]

Oldfield RC. The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia 1971;9:97–113. [PubMed: 5146491]

Osterhout L, Bersick M, McKinnon R. Brain potentials elicited by words: word length and frequency predict the latency of an early negativity. Biol. Psychol 1997;46:143–168. [PubMed: 9288411]

Pacht JM, Rayner K. The processing of homophonic homographs during reading: evidence from eye movement studies. J. Psycholinguist. Res 1993;22:251–271. [PubMed: 8366477]

Perani D, Cappa SF, Schnur T, Tettamanti M, Collina S, Rosa MM, et al. The neural correlates of verb and noun processing. A PET study. Brain 1999;122(12):2337–2344. [PubMed: 10581226]

Pierce RS, Beekman LA. Effects of linguistic and extralinguistic context on semantic and syntactic processing in aphasia. J. Speech Hear. Res 1985;28:250–254. [PubMed: 2409351]

Preissl H, Pulvermuller F, Lutzenberger W, Birbaumer N. Evoked potentials distinguish between nouns and verbs. Neurosci. Lett 1995;197:81–83. [PubMed: 8545063]

Pulvermuller F. Brain reflections of words and their meaning. Trends Cogn. Sci 2001;5:517–524. [PubMed: 11728909]

Pulvermuller F, Preissl H, Lutzenberger W, Birbaumer N. Brain rhythms of language: nouns versus verbs. Eur. J. Neurosci 1996;8:937–941. [PubMed: 8743741]

Pulvermuller F, Lutzenberger W, Preissl H. Nouns and verbs in the intact brain: evidence from event-related potentials and high-frequency cortical responses. Cereb. Cortex 1999a;9:497–506. [PubMed: 10450894]

Pulvermuller F, Mohr B, Schleichert H. Semantic or lexico-syntactic factors: what determines word-class specific activity in the human brain? Neurosci. Lett 1999b;275:81–84. [PubMed: 10568504]

Reynolds A, Flagg P. Recognition memory for elements of sentences. Mem. Cogn 1976;4:422–432.

Seidenberg MS, Tanenhaus MK, Leiman JM, Bienkowski M. Automatic access of the meanings of ambiguous words in context: some limitations of knowledge-based processing. Cogn. Psychol 1982;14:489–537.

Shapiro K, Caramazza A. Grammatical processing of nouns and verbs in left frontal cortex? Neuropsychologia 2003;41:1189–1198. [PubMed: 12753958]

Simpson GB, Krueger MA. Selective access of homograph meanings in sentence context. J. Mem. Lang 1991;30:627–643.

Soros P, Cornelissen K, Laine M, Salmelin R. Naming actions and objects: cortical dynamics in healthy adults and in an anomic patient with a dissociation in action/object naming. NeuroImage 2003;19:1787–1801. [PubMed: 12948733]

Swinney D, Hakes D. Effects of prior context upon lexical access during sentence comprehension. J. Verbal Learn. Verbal Behav 1976;15:681–689.

Tanenhaus MK, Donnenwerth-Norlan S. Syntactic context and lexical access. Q. J. Exp. Psychol 1984;36A:649–661.

Tanenhaus MK, Leiman JM, Seidenberg MS. Evidence for multiple stages in the processing of ambiguous words in syntactic contexts. J. Verbal Learn. Verbal Behav 1979;18:427–440.

Thios S. Memory for general and specific sentences. Mem. Cogn 1975;3:75–77.

Tranel D, Martin C, Damasio H, Grabowski TJ, Hichwa R. Effects of noun-verb homonymy on the neural correlates of naming concrete entities and actions. Brain Lang 2005;92:288–299. [PubMed: 15721961]

Tyler LK, Russell R, Fadili J, Moss HE. The neural representation of nouns and verbs: PET studies. Brain 2001;124:1619–1634. [PubMed: 11459753]

Tyler LK, Bright P, Fletcher P, Stamatakis EA. Neural processing of nouns and verbs: the role of inflectional morphology. Neuropsychologia 2004;42:512–523. [PubMed: 14728923]

Van Petten, C. Lexical ambiguity resolution. In: Nadel, L., editor. Encyclopedia of Cognitive Science. London: Macmillan; 2002. p. 867-872.

Van Petten C, Kutas M. Ambiguous words in context: an event-related potential analysis of the time course of meaning activation. J. Mem. Lang 1987;26:188–208.

Van Petten C, Kutas M. Interactions between sentence context and word frequency in event-related brain potentials. Mem. Cogn 1990;18:380–393.

Van Petten C, Kutas M. Influences of semantic and syntactic context on open- and closed-class words. Mem. Cogn 1991;19:95–112.

Warburton E, Wise RJ, Price CJ, Weiller C, Hadar U, Ramsay S, et al. Noun and verb retrieval by normal subjects. Studies with PET. Brain 1996;119(1):159–179. [PubMed: 8624678]

Wearing A. The recall of sentences of varying length. Aust. J. Psychol 1973;25:155–161.

West WC, Holcomb PJ. Imaginal, semantic and surface-level processing of concrete and abstract words: an electrophysiological investigation. J. Cogn. Neurosci 2000;12:1024–1037. [PubMed: 11177422]

Wilson, M. Informatics Division Science and Engineering Research Council Rutherford Appleton Laboratory Chilton. Didcot: Oxon; 1987. MRC psycholinguistic database: machine usable dictionary. Version 2.00. OX11 0QX 1.

Woods SP, Carey CL, Troster AI, Grant I. Action (verb) generation in HIV-1 infection. Neuropsychologia 2005;43:1144–1151. [PubMed: 15817172]

Zingeser LB, Berndt RS. Retrieval of nouns and verbs in agrammatism and anomia. Brain Lang 1990;39:14–32. [PubMed: 2207618]

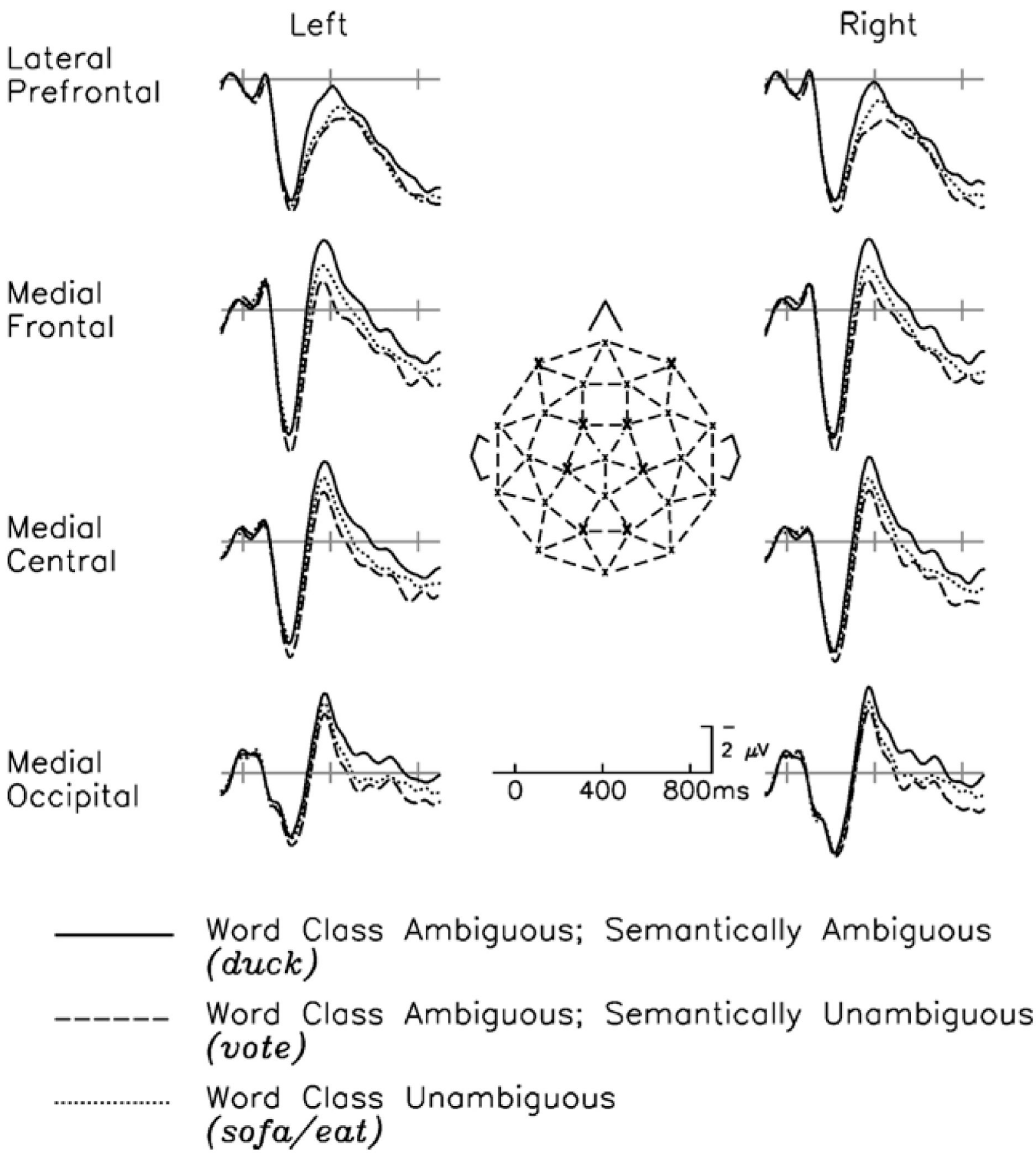

Fig. 1.
ERP responses to word class and semantically ambiguous words (solid line), word class ambiguous but semantically unambiguous words (dashed line), and word class unambiguous words (dotted line) at eight representative electrodes across the scalp. Positions of the plotted sites are indicated by larger Xs on the small head diagram. Negative is up for this figure and all subsequent ones. Over fronto-central scalp sites, the response to word class and semantically ambiguous words (e.g., ‘duck’) is more negative than the response to word class ambiguous but semantically unambiguous words (e.g., ‘vote’) from around 250 ms to 900 ms post-stimulus-onset, and the response to word class ambiguous but semantically unambiguous

words (e.g., ‘vote’) is more positive than the response to class unambiguous words (e.g., ‘sofa/eat’) in the early part of this time window (250–500 ms).

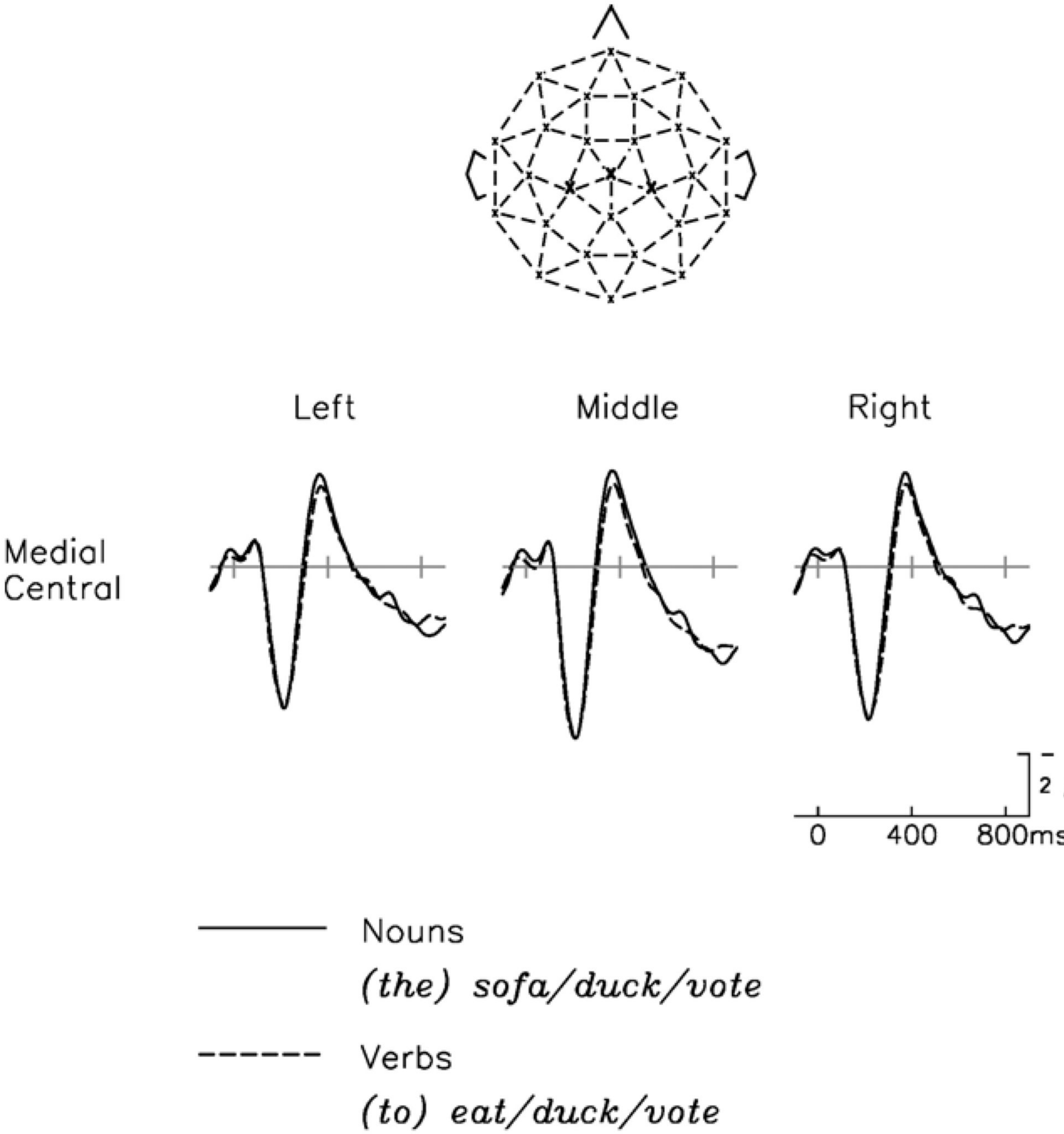

Fig. 2.
Word class effects for nouns and verbs at three representative medial central sites. Nouns are associated with a larger negativity (N400, 250–450 ms) than verbs.

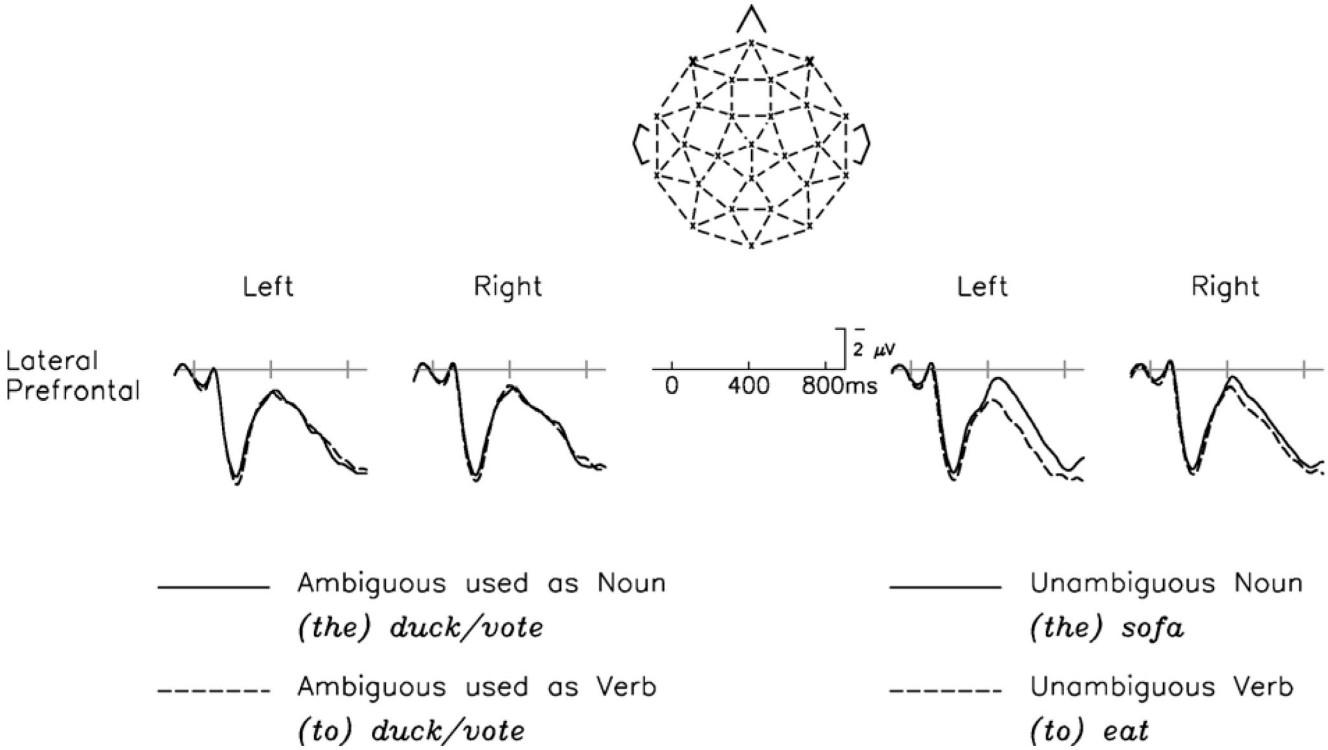

Fig. 3.
Word class effects for unambiguous (right) and ambiguous (left) items at two representative lateral prefrontal electrode sites. There is an enhanced frontal positivity to unambiguous verbs as compared with unambiguous nouns from 300 to 700 ms post-stimulus-onset. Note that this effect does not show up for the comparison between the class ambiguous pairs.