Electrophysiological signatures of event words: Dissociating syntactic and semantic category effects in lexical processing

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ABSTRACT

Numerous theories have been proposed regarding the brain's organization and retrieval of lexical information. Neurophysiological dissociations in processing different word classes, particularly nouns and verbs, have been extensively documented, supporting the contribution of grammatical class to lexical organization. However, the contribution of semantic properties to these processing differences is still unresolved. We aim to isolate this contribution by comparing ERPs to verbs (e.g. *wade*), object nouns (e.g. *cookie*), and event nouns (e.g. *concert*) in a paired similarity judgment task, as event nouns share grammatical category with object nouns but some semantic properties with verbs. We find that event nouns pattern with verbs in eliciting a more positive response than object nouns across left anterior electrodes 300–500 ms after word presentation. This time-window has been strongly linked to lexical-semantic access by prior electrophysiological work. Thus, the similarity of the response to words referring to concepts with more complex participant structure and temporal continuity extends across grammatical class (event nouns and verbs), and contrasts with the words that refer to objects (object nouns). This contrast supports a semantic, as well as syntactic, contribution to the differential neural organization and processing of lexical items. We also observed a late (500–800 ms post-stimulus) posterior positivity for object nouns relative to event nouns and verbs at the second word of each pair, which may reflect the impact of semantic properties on the similarity judgment task.

1. Introduction

1.1. Background

Human language comprehension is dependent on a stored bank of bindings between semantic, syntactic, and word form information, usually referred to as the lexicon. For example, in English the lexical item corresponding to the form *cookie* is usually assumed to belong to the syntactic category of nouns – a category of items that appear in specific environments, such as after an adjective or before a verb – and the semantic category of objects or entities. Inspired by well-replicated neuropsychological dissociations between nouns and verbs, many theories have proposed that the spatial distribution of lexical knowledge in the cortex is organized along grammatical and/or conceptual dimensions (e.g. Caramazza and Hills, 1991; see Vigliocco et al. (2011) for review). Syntactic organization (e.g. by grammatical category) would predict dissociations between nouns and verbs — or, in theories that dispense with grammatical categories per se (Marantz, 1997), so would lexical organization according to the frequency with which roots

combine with particular grammatical category heads. However, nouns and verbs also tend to differ on a number of semantic properties. In particular, most nouns refer to single entities without temporal extent while most verbs refer to concepts that have temporal boundaries, even if unspecified. The meaning of most verbs also specifies relations between entities (in contrast to many nouns), which may or may not be syntactically required.

The hypothesis that lexical information is organized according to grammatical or semantic category has been investigated by much previous work contrasting the neural response to nouns and verbs. As this hypothesis would predict, numerous EEG studies report reliable differences between nouns and verbs within the ~200–500 ms post-stimulus time-window, in which lexical activation and selection are generally thought to occur. Most prominently, these studies report more positive potentials for verbs than nouns in left frontal electrodes beginning around 200–250 ms post-stimulus onset, an effect sometimes described as a 'verb-enhanced positivity' (Dehaene, 1995; Preissl et al., 1995; Federmeier et al., 2000; Lee and Federmeier, 2006). This effect persists when the target word is presented within sentences

(Federmeier et al., 2000) or in minimal phrases (Lee and Federmeier, 2006), as well as across a variety of experimental tasks such as lexical decision (Preissl et al., 1995), semantic categorization (Dehaene, 1995), and passive reading followed by comprehension probes (Federmeier et al., 2000). Additionally, several studies report an effect with similar timing and directionality (verbs more positive than nouns) over centro-parietal electrodes (Federmeier et al., 2000; Lee and Federmeier, 2006; Barber et al., 2010), which has been ascribed to differences in the N400 response, a component thought to reflect lexical and semantic memory processes (Kutas and Federmeier, 2011).

While dissociations in the brain regions supporting noun and verb processing have been studied extensively, the resulting picture is complex. Lesion studies, which initially associated verbs with left frontal and nouns with left temporal areas (e.g. Damasio and Tranel, 1993), have continued to reliably show double dissociations in the processing of these word classes, but with further work it has become clear that the deficits emerge from a number of anatomical lesion configurations. A larger fronto-temporo-parietal network has been implicated in verb retrieval, while object noun deficits are more consistently localized to regions of the temporal lobe (see Crepaldi et al. (2011) for a review). In the functional neuroimaging literature, many studies have contrasted nouns and verbs, employing a variety of paradigms – picture naming, semantic judgment, lexical decision – and the regions implicated are variable and appear to be influenced by the task (Crepaldi et al., 2011; Vigliocco et al., 2011). In an influential review, Vigliocco et al. (2011) argue that effects of grammatical category per se are mainly observed in tasks that require morphosyntactic processing or syntactic integration (with increased activity for verbs in left inferior frontal areas). On the other hand, tasks that recruit semantic knowledge (word generation, picture naming, semantic judgment) emphasize the contribution of semantic differences, such that neural dissociations by grammatical category less salient if the critical semantic differences are controlled. For example, Vigliocco et al. (2006) report anterior temporal activation to sensory words (e.g. *tickle*), and primary motor cortex activation to motion words (e.g. *run*). Whether or not this particular framework is adopted, it seems clear that the neuroimaging data shows impacts of both grammatical class and semantic properties on the contrast between noun and verb processing.

In the current study, we investigate the hypothesis that semantic properties also influence early stages of lexical access, and dissociate them from the grammatical category distinction between nouns and verbs. This hypothesis can be most directly evaluated with a subcategory of nouns that we will refer to as *event nouns*, as illustrated by Bedny et al. (2013). Like many verbs, these nouns denote actions, processes, or events, and often implicitly relate entities to actions and to one another. For example, *concert* presumes, at the least, an action (performing), an agent of that action (performer), and a patient (audience); thus there is also a presumed relation between the entities. Such a concept also entails a temporal dimension, a property shared with verbs – a concert extends in time, and will have temporal boundaries, though unspecified. The similarities between event nouns and verbs can also be observed in the way other categories interact with them – e.g. event nouns may be modified by adjectives with meanings similar to that of adverbs (e.g. *annual concert* and *rotate annually* vs. the incongruent *annual cucumber*).

Because event nouns share grammatical properties with nouns but semantic properties with verbs, they make it possible to dissociate the contribution of syntactic and semantic properties to the activity indexing categorical differences in the perception of lexical items. Bedny et al. (2013) compared the response to event nouns in fMRI with more canonical 'object' nouns and verbs (animal nouns, plant nouns, emission verbs, motion verbs, and perception verbs) presented in short phrasal contexts (*the/to* ____). A similarity judgment task was used (rating subjective similarity for each trial of two stimuli, which were always from the same subcategory) in order to encourage full lexico-semantic access of each item. Critically, in addition to a main effect of grammatical category in the left posterior superior temporal gyrus (STG), Bedny et al. (2013) provided evidence that differences in the left posterior middle temporal gyrus (MTG) reflected semantic as well as syntactic properties, as both verbs and event nouns elicited more activity in this region than object nouns. Further evidence of semantic influence is seen from neurophysiological lesion studies, which show that some patients with verb naming difficulties also have difficulties with event nouns; such patients are reported to have relatively heterogeneous lesions within left frontal and temporo-parietal cortices (Tabossi et al., 2010; Collina et al., 2001). However, some of these studies have used morphologically complex stimuli that have verbal roots, which may confound the semantics-syntax dissociation (e.g. *confession*; Tabossi et al., 2010). This body of evidence suggests that abstract semantic properties, in addition to syntactic categorization, play a role in neural representation and retrieval of lexical items, however, the dissociation between semantic and syntactic influence is still unclear.

One previous ERP study by Barber et al. (2010), investigated the response to morphologically complex nouns and verbs that described events (e.g. *corsa* – the run; *correre* – to run) selected to evoke either sensory (e.g. *the smell, to sniff*) or motor concepts (e.g. *the pirouette, to hike*). Barber et al. found effects in the 300–450 ms time-window for both the grammatical and the semantic manipulation (more posterior negativity for nouns than verbs, and for sensory than motor words), and concluded that differences in meaning retrieval could be the driving force behind both observed effects. However, this study was not aimed at investigating the impact of the event/entity distinction on lexical-semantic processing and therefore did not include non-event words for comparison.

1.2. The current study

As reviewed above, prior ERP studies have demonstrated relatively early processing differences between typical nouns and verbs, most reliably evidenced in an increased left anterior positivity for verbs relative to nouns at ~300 ms post-stimulus onset. Here we use Bedny et al.'s event noun manipulation to ask whether such processing differences may be at least partially attributable to abstract semantic properties rather than grammatical category per se. Specifically, we investigate the impact of semantic factors (entity e.g. *elephant* as opposed to event e.g. *concert*), in addition to grammatical class (noun e.g. *hurricane* vs. verb e.g. *persuade*), on early stages of lexical-semantic access. Bedny et al.'s fMRI study demonstrates that abstract semantic properties drive differential neural responses to nouns and verbs. However, due to the lack of temporal sensitivity of fMRI it is difficult to determine whether the observed differences reflect the early stages of lexical access or later stage processes such as those involved in the end-of-trial similarity judgment. Our current paradigm uses EEG, a method with high temporal resolution, in order to determine the timecourse of the dissociations.

An important modification of Bedny et al.'s (2013) design was that we do not use syntactic context words to mark verbs and nouns (*to/the*). This ensures that any differences observed between verbs and nouns are not due to the preceding phrasal context. As in Bedny et al. (2013), we relied on corpus counts to minimize grammatical category ambiguity to the greatest extent possible; this is especially important for ERPs because prior work has demonstrated interactions between grammatical category and category ambiguity (Federmeier et al., 2000; Lee and Federmeier, 2006). Finally, in order to draw the conclusion that the patterning together of event nouns and verbs reflects shared semantic properties rather than grammatical category, it is important to be confident that the event nouns do not contain a verbal root that might be decomposed in processing. While the majority of Bedny et al.'s items did not contain verbal roots, in the current study we were even more stringent in excluding such cases. Aside from these stimuli