Neuropsychologia 93 (2016) 151–157

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

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

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ARTICLE INFO

Keywords:
Language
EEG
ERP
Semantics
Syntax
Word class

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

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http://dx.doi.org/10.1016/j.neuropsychologia.2016.10.014
Received 13 June 2016; Received in revised form 3 October 2016; Accepted 22 October 2016
Available online 26 October 2016
0028-3932/

(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

modifications, we retained the experimental design of Bedny et al.

2. Experimental procedure

2.1. Materials

Stimuli consisted of 50 words in each of the following categories: event nouns (eg. *concert*), verbs (eg. *rotate*), and object nouns (eg. *tiger*). The full stimuli list is presented in Supplementary Table 1. The items were adapted from Bedny et al. (2013), with the following modifications: the object noun category included 20 members of animal and plant noun categories of Bedny et al., with 30 novel additions; the verb category included 33 members of perception and manner of motion verbs categories with 17 novel additions; the event noun category included 35 event nouns from Bendy et al. with 15 novel additions. As in Bedny et al. (2013): syntactic category ambiguity was minimized, and event nouns that could be semi-transparently related to verbs were excluded. Morphological complexity was avoided, as it may impose additional processing demands. In the current study lexical frequency was matched across categories, because ERP responses such as the N400 demonstrate reliable effects of frequency (e.g. Van Petten and Kutas, 1990; Van Petten et al., 1991). Bedny et al. (2013) mismatched word frequency across categories in order to control for behavioral difficulty, which is critical in fMRI where it is more difficult to dissociate initial processing from response processing. Lexical usage frequency was matched through the number of appearances in the Corpus of Contemporary American English 27 (COCA; Davies, 2008). The corpus consists of 450 million words from spoken and written materials, and usage frequency refers to the number of times a word appears within the corpus. The frequency counts were as follows. Event nouns: mean=11,036, s.d.=15,050; object nouns: mean=11,134, s.d.=15,187; verbs: mean=11,588, s.d.=12,743. The conditions were also matched for word length (event nouns: mean=7.22, s.d.=1.59; object nouns: mean=6.94, s.d.=1.85; verbs: mean=6.92, s.d.=1.77).

To ensure that subjects interpreted words as belonging to the intended grammatical category, we chose only words that were used 10 times more often in the desired grammatical category. 24 of 50 verbs had some noun usage (overall verb-to-noun ratio 1324.7); 7 of 50 event nouns had some verb usage (overall noun-to-verb ratio 8134.2); 11 of 50 object nouns had some verb usage (overall noun-to-verb ratio 2184.9). Note that, if anything, there were more verb uses in the corpus within our set of object nouns than event nouns. Words with multiple unrelated meanings within the same category (e.g. *crane*) were also excluded.

After stimulus selection, the 150 test words were organized into a list of pairs such that both pair members came from the same category. Each word appeared on the list twice, each time paired with a different other word, and once as the first and once as the second word of the pair. The pairings as well as the order of pairs on the list were randomized. Four randomization versions of the stimuli pair list were generated. Each participant was presented with one of the four versions, with an equal number of participants seeing each version.

2.2. Participants

Participants were University of Maryland students who participated in the study for monetary compensation or course credit. Prior written consent was obtained from all participants according to the established guidelines of the Institutional Review Board of the University of Maryland. All participants were native speakers of American English and were right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). In total, 26 participants took part in the study, but two datasets were excluded due to excessive artifacts. 24 participants were included in the dataset analyzed here (13 female; mean age=20.3, s.d.=1.4).

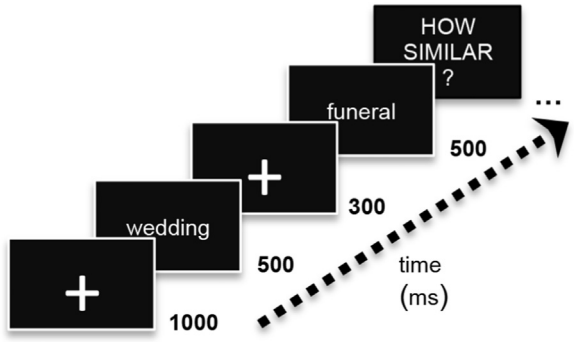

Fig. 1. Trial structure. Pairs of words from the same category were presented visually, one word at a time, followed by a similarity judgment prompt which remained onscreen until an evaluation was made.

2.3. Procedure

Participants were seated approximately 2′ away from a 16″ computer screen. Stimuli were visually presented in 24-point white font on a black background in the center of the screen using Psychtoolbox for Matlab (Brainard, 1997; Pelli, 1997; Kleiner et al., 2007). Stimulus pairs were presented in 3 blocks of 50 pairs each, and participants were asked to rate their similarity in meaning on the scale of 1 (dissimilar) to 4 (similar). Each trial began with a 1000 ms fixation cross, followed by the stimulus words one at a time. Each word remained on screen for 500 ms, with a 300 ms inter-word interval. Each pair was followed by the phrase “How similar? ” 300 ms after the second word, which remained on the screen until the participant entered a similarity rating (Fig. 1).

2.4. Electrophysiological recording

Twenty-nine tin electrodes were held in place on the scalp by an elastic cap (Electro-Cap International, Inc., Eaton, OH) in a 10–20 configuration (O1, Oz, O2, P7, P3, Pz, P4, P8, TP7, Cp3, CPz, CP4, TP8, T7, C3, Cz, C4, T8, FT7, FC3, FCz, FC4, FT8, F7, F3, Fz, F4, F8, FP1). Bipolar electrodes were placed above and below the left eye and at the outer canthus of both eyes to monitor vertical and horizontal eye movements. Additional electrodes were placed over the left and right mastoids. Scalp electrodes were referenced online to the left mastoid and re-referenced offline to the average of left and right mastoids. Impedances were maintained at less than 5 kΩ for all scalp and mastoid electrode sites, and less than 10 kΩ for ocular electrodes. The EEG signal was amplified by a NeuroScan SynAmps® Model 5083 (NeuroScan, Inc., Charlotte, NC) with a bandpass of 0.05–100 Hz and was continuously sampled at 500 Hz by an analog-to-digital converter.

2.5. ERP data processing

For each word of the pair, averaged ERPs time-locked to stimulus onset were computed for the 100 ms pre- to 800 ms post- stimulus-onset time window from trials free of ocular and muscular artifact using preprocessing routines from the EEGLAB (Delorme and Makeig, 2004) and ERPLAB (erpinfo.org/erplab) toolboxes. On average, 14% of epochs were rejected for each participant due to artifacts. Two participants with rejection rates of 42% and 57% were excluded. Rare cases of single channels with a disproportionate number of epochs (~40% or more) containing peak-to-peak fluctuations of 100 μV or more were noted. Such channels were excluded, and their values were then interpolated. The interpolation was carried out using the EEGLAB software package, by spherical spline interpolation, which took into account all other channels in the dataset not marked for exclusion. The affected channels were O1 (4 participants), OZ (3 participants), O2, F8, FT7 (2 participants each), and F7, T7, and Pz

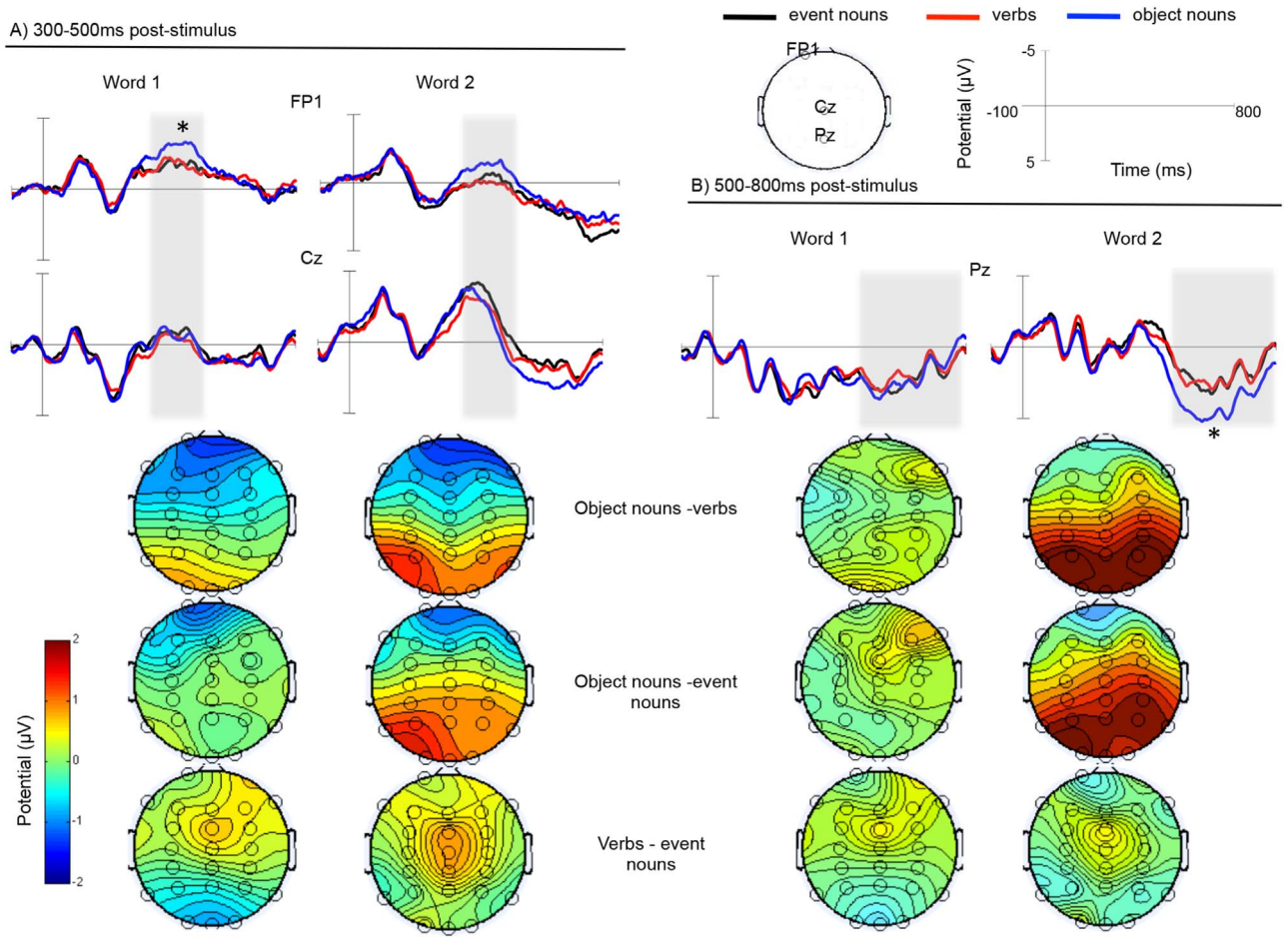

Fig. 2. Electrophysiological results. Grand average ERP responses (participants n=24) at representative electrodes and topographical distribution of differences between conditions within a time window of interest. Time 0 is the onset of each stimulus. A) Responses 300–500 ms post word onset. Object nouns elicited more negativity relative to event nouns and verbs ($p < 0.05$ for both pairwise contrasts) in the left anterior regions. B) Responses 500–800 ms post word onset. Object nouns elicited more positivity than either event nouns or verbs ($p < 0.01$ for both pairwise contrasts).

(1 participant each). No more than 3 channels were interpolated for any one participant, and only one instance of interpolation occurred for the channels in the anterior ROI (F7). A 100 ms pre-stimulus baseline was subtracted from the waveforms,[1] and a low-pass filter (40 Hz) was applied before ERP computation.

The two words in the pair were analyzed separately because of the potentially differential impact of the similarity judgment task on the first and second word; little task-related processing could happen on the first word, but the similarity assessment could begin as soon as the second word was presented. One-way repeated measures ANOVAs (across 3 levels of word class) were conducted on the 300–500 ms time-window in two regions of interest (ROIs), which were identified based on the location and timing of previously reported word category effects (Federmeier et al., 2000; Lee and Federmeier, 2006): "verb-related positivity" ROI (FP1, F7 and F3) and a central/posterior N400 ROI (C3, Cz, C4, CP3, CPz and CP4). A third, exploratory ROI, was identified based on visual inspection of the current data, which revealed large differences between conditions with a broad posterior distribution and a timing characteristic of many late positivities observed in language comprehension tasks. We conducted an exploratory analysis in the 500–800 ms time-window in a broad posterior ROI (TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, O2). Significant effects of word class were followed up with pairwise comparisons between conditions.

3. Results

3.1. Left anterior effects, 300–500 ms

Left anterior ERPs to verbs and event nouns were more positive than to object nouns between 300–500 ms, but this difference was more marked for the first word of the pair than the second (Fig. 2). For the first word of the pair, a repeated measures ANOVA showed a significant effect of word class ($F(2,46)=3.61$, $p=0.02$). In line with previous findings, subsequent pairwise comparisons showed a significant difference between object nouns and verbs ($F(1,23)=6.07$, $p=0.02$). Critically, we observed a significant difference between object nouns and event nouns ($F(1,23)=4.32$, $p < 0.05$), but not event nouns and verbs ($F(1,23)=0.27$, $p=0.60$). The second word of the pair showed the same numerical pattern, although the main effect of word class did not reach significance ($F(2,46)=1.86$, $p=0.17$).

3.2. Central/posterior effects, 300–500 ms (N400)

In the central region of interest, there was a very slight numerical tendency for the noun conditions to be more negative than the verb

[1] One potential concern is that differences in the response to the first word of the pair could contaminate the baseline for the second word of the pair. While this is unlikely because of the long stimulus-onset asynchrony (800ms), we also conducted a supplementary analysis in which both words were included in a single long 1600ms epoch, which yielded essentially the same pattern of results for the second word.

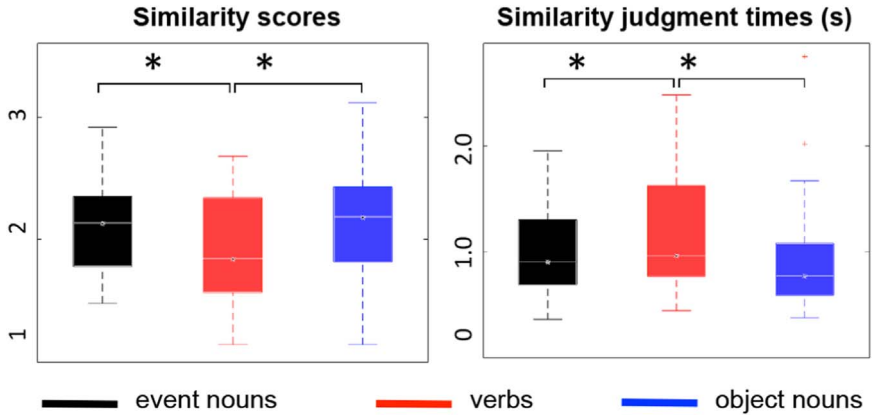

Fig. 3. Behavioral results. Verb pairs were judged as less similar (scale 1–4) than either event or object nouns ($p < 0.01$ for both pairwise contrasts). Similarity judgment times for verbs were longer than either event or object nouns ($p < 0.01$ for both contrasts).

condition, but ANOVAs showed no significant effects of word class for either word position (W1: $F(2,46)=0.21$, $p=0.81$; W2: $F(2,46)=1.85$, $p=0.17$).

3.3. Posterior effects, 500–800 ms

Although not reported by prior ERP work examining category effects, visual inspection indicated a much larger late posterior positivity for object nouns compared to the other two conditions in the ERPs to the second word of the pair. Therefore we conducted analyses across posterior electrodes in the 500–800 ms time-window in order to evaluate the reliability of these effects across participants. A robust effect of word class was indeed observed in the second word of the pair ($F(2,46)=16.23$, $p < 0.01$), but not in the first word of the pair ($F(2,46)=0.43$, $p=0.65$). Follow-up pairwise comparisons for the second word of the pair revealed significant differences between object nouns and verbs ($F(1,23)=19.38$, $p < 0.01$), and object nouns and event nouns ($F(1,23)=23.49$, $p < 0.01$), but no significant difference between verbs and event nouns ($F(1,23)=0.22$, $p=0.65$). It is important to note that this posterior ROI was identified post-hoc, based on the current data and the results should therefore be taken as exploratory because they are subject to Type I error inflation.

3.4. Behavioral data

3.4.1. Similarity judgments

Across subjects, the mean similarity rating was 2.11 for event nouns (s.d.=0.38), 1.92 for verbs, (s.d.=0.46) and 2.15 for object nouns (s.d.=0.46). A repeated measures ANOVA showed a significant effect of word class ($F(2,46)=2.61$, $p < 0.01$). Pairwise comparisons indicated that verb pairs were rated as significantly less similar than object noun pairs ($t(1,23)=2.89$, $p < 0.01$), or event noun pairs ($t(1,23)=-4.91$, $p < 0.01$). Judgments for object and event nouns did not reliably differ ($t(1,23)=0.53$, $p=0.60$). Note that this behavioral difference does not follow what was observed in the ERP data, where the event nouns pattern with the verbs.

3.4.2. Reaction times

Reaction times for the judgments, defined as the time between the onset of "How similar?" and the similarity judgment button press, were also evaluated. The results were as follows: event nouns, mean=1000 ms (sd=420 ms); verbs, mean=1150 ms (sd=570 ms); object nouns, mean=940 ms (sd=570 ms). A repeated measures ANOVA showed a significant effect of word class ($F(2,46)=6.31$, $p < 0.01$). Pairwise comparisons showed that reaction times were significantly longer for verbs than object nouns ($t(1,23)=2.98$, $p < 0.01$) or event nouns ($t(1,23)=3.72$, $p < 0.01$). Object and event nouns did not significantly differ in reaction time ($t(1,23)=-0.89$ $p=0.38$).

In sum, we observed that verb pairs were rated slightly but significantly less similar than the other two conditions, and the reaction time to compute this judgment was significantly longer for verbs than for the other two conditions. However, these behavioral differences do not pattern with the observed ERP effects, in which it was the object noun condition that consistently diverged from the other two conditions (Fig. 3).

4. Discussion

The aim of the current study was to determine whether differences in the ERP response to nouns and verbs reflect, at least in part, their different semantic properties rather than grammatical category per se. In particular, we tested whether event nouns, which share semantic properties with verbs, would pattern with verbs or with object nouns during early lexical access. Although previous ERP work has reliably demonstrated more positive responses for unambiguous verbs than nouns in left anterior electrodes beginning ~250 ms post-stimulus (Dehaene, 1995; Federmeier et al., 2000; Lee and Federmeier, 2006), it has been unclear which grammatical or semantic distinctions between nouns and verbs are driving these processing differences. We observed that event nouns and verbs patterned together in being significantly less negative than object nouns in the time-window of 300–500 ms post-stimulus.

The current results demonstrate that semantic properties are an important contributor to this effect, and in particular, that the increased left anterior positivity is associated with some property of words that denotes temporal boundaries and/or relates entities to each other. The relatively early onset of this effect, in a time-window that much ERP work has associated with lexical/conceptual memory access, is consistent with the hypothesis that the semantic properties in question impact lexical organization and/or retrieval processes – that is, that certain semantic properties common to verbs and event nouns are accessed during this time-window. These results also converge with the results of a previous fMRI investigation of event nouns (Bedny et al., 2013), which identified a posterior middle temporal region whose activity increased for verbs and event nouns relative to object nouns.

As discussed in the introduction, exactly what is the critical semantic property that differentiates the processing of verbs and event nouns from object nouns remains an open and interesting question for future research. One possibility is the property of temporal extent: events are defined in some region of time and include implicit temporal boundaries in their meaning, while objects do not. The neural effects observed could reflect the retrieval or processing of this temporal information. Another possibility is the property of semantic relationality. Highly relational lexical items require, or presume, entities and concepts that are separate from themselves. Event nouns, unlike verbs, do not require syntactic arguments, but they do invoke semantic

relations. For example, *rodeo* presumes several individuals and a location. Invoking semantic relations is a property event nouns share with verbs, but not object nouns (*apple* does not presume other entities), therefore electrophysiological dissociation of event nouns and verbs from object nouns may index greater activation from accessing these relations. A third possibility is the property of concreteness: event nouns and verbs are less concrete than object nouns, and processing concrete words might systematically differ from processing abstract words. Many previous ERP studies have demonstrated more negative responses for concrete words than abstract words (e.g. Kounios and Holcomb, 1994; Lee and Federmeier, 2008), which is similar to the current pattern of object nouns (more concrete) eliciting more negative responses than event nouns and verbs (more abstract). However, we note that these concreteness effects are generally more widely distributed across the scalp than the relatively focal word class effect observed here. Similarly, in neuroimaging experiments the neuroanatomical distribution of abstractness effects is distinct from the verb and event noun responses (e.g. Wang et al., 2010, Bedny et al., 2013). In future studies it will be important to directly compare processing of verbs and event nouns to abstract non-event nouns.

These results also suggest that the left anterior contrast between nouns and verbs observed in ERP is robust to stimulus context and task. In many previous ERP studies (Dehaene, 1995; Federmeier et al., 2000; Lee and Federmeier, 2006), the critical word class stimuli were presented in context, either in full sentences or minimal phrases (*the/to* _____). These studies also used different tasks, such as judging similarity of a probe word or paraphrase to the prior stimuli. Here, we replicated the effect with a paired similarity judgment task, while presenting unambiguous nouns and verbs with no syntactic context at all. These results suggest that although context and task may facilitate word class processing and thus modulate the latency or the duration of word class effects (Lee and Federmeier, 2006), syntactic context is not necessary to elicit the processing differences observed between words carrying a temporal and/or relational semantic structure and single-entity words over left anterior electrode sites in ERP. At the same time, it is possible that the absence of syntactic context in the current study explains our lack of independent ERP effects of grammatical category; this is an interesting question for future investigation.

Some previous ERP studies have also observed what appears to be an increased N400 response for nouns relative to verbs over centro-parietal electrodes in a similar time-window (Federmeier et al., 2000; Lee and Federmeier, 2006). Although there was a slight numerical tendency in this direction in the current dataset, it was not reliable. The most probable explanation for this discrepancy is that in contrast to the left anterior effects, these N400 category effects critically depend on context. Federmeier and colleagues (2000) used full sentence contexts, while Lee and Federmeier (2006) used only minimal one-word contexts, and Lee and Federmeier note that this might explain why N400 effects were notably larger in the earlier study. N400 amplitudes are highly sensitive to the predictability of the critical word given the prior context (see Kutas and Federmeier (2011), for review). If prior context differentially modulates expectations for particular nouns and verbs (perhaps related to the fact that there are many more nouns than verbs in English), it could account for the N400 effects observed in prior studies and the absence of significant N400 effects in the current study, which presented the target words without prior context.

The current ERP study adapted a paradigm used by Bedny et al. (2013), which found that both event nouns and verbs showed more activity than object nouns in the left posterior middle temporal gyrus. Our finding that event nouns and verbs similarly pattern together over left anterior electrodes between 300 and 500 ms can be taken as suggestive evidence about the timecourse of the left pMTG dissociation that Bedny et al. observed in fMRI. However it is important to note that the link between the current ERP results and the prior fMRI results is tentative for several reasons. First, we also observed event nouns and verbs patterning together against object nouns in a later time-window over posterior electrodes for the second word of each trial, appearing to reflect category effects on a mechanism associated with the judgment task. Since fMRI has limited temporal resolution, there is no way of differentiating whether the left pMTG effect that Bedny et al. observed is related to the late posterior effect or the early left anterior effect. Because EEG source localization is relatively poor (especially without a high-density array), it would be challenging to use the surface topographical distribution of these effects to determine their likely source. Second, the very different physiological mechanisms underlying fMRI and EEG measurement make it a possibility that the same paradigm in fMRI and EEG will elicit effects with completely non-overlapping sources. The MEG technique, which provides better spatial resolution than EEG yet retains its high temporal resolution, provides a good means for evaluating these possibilities and providing a critical link between the prior and current findings.

In the current study, participants' task was to evaluate the similarity of the two (same-category) words presented in each trial. At the second word only, we observed a large dissociation in amplitude over posterior electrodes between object nouns and the two other categories beginning at ~500 ms such that amplitudes were significantly more positive for object nouns. The absence of this effect at the first word strongly suggests that it reflects the impact of category on some aspect of executing the judgment task. This effect is similar in timing and distribution to the P600 component often observed in response to sentence-level syntactic, semantic, and orthographic violations (Osterhout and Holcomb, 1992; Kolk et al., 2003; Vissers et al., 2006), which is also modulated by task demands (Kuperberg, 2007). Although a matter of continued debate, the P600 has most recently been argued to index higher-level processes such as conflict monitoring, reprocessing, or detection of prediction error (e.g. van de Meerendonk et al., 2009; Kuperberg, 2013). The P600 may be a variant of the domain-general P3b response (e.g. Coulson et al., 1998), which is similarly associated with prediction error (Kutas et al., 1977; Johnson and Donchin, 1980) and thought to reflect corresponding working memory update (Donchin and Coles, 1988).

Electrophysiological effects of interaction between similarity judgment task and semantic category have not previously been reported, and our behavioral data does not pattern with this late effect; therefore, our account of its cause is speculative. One possibility is that the observed ERP dissociation may be indicative of varying strategies used in evaluation. Participants reported that they used semantic features to compare nouns, but were less able to report details of the strategy they used for evaluating verbs and event nouns. Therefore, perhaps the resemblance to the P600 and P3b components suggests a strategy in the object noun condition in which the semantic features of the first word were predicted for the second word, and where degree of prediction error would be used to inform the judgment. Alternatively, perhaps the greater effort when evaluating similarity of more abstract concepts leads to increased late *negativity* in the verb and event noun conditions. As the focus of the current study was the impact of semantic properties on early lexical retrieval processes that should be relatively independent of task, we leave this question for future work.

5. Conclusions

We investigated the contribution of semantic properties to word class dissociations in processing. We compared the response to object nouns and verbs to a subclass of nouns denoting events, which shares semantic properties with verbs despite sharing grammatical category with other nouns. We replicated previous reports of an early left anterior dissociation between object nouns and verbs, and we found that event nouns clearly pattern with verbs rather than object nouns. These results indicate that the distinction between words that refer to entities and words that refer to concepts with more complex semantic relationality or temporal extent has an important impact on lexical-

semantic access processes in the 300–500 ms window post-stimulus, and suggest a promising new area of investigation towards developing more fine-grained models of lexical organization and retrieval.

Acknowledgments

We thank Anna Namyst, Amina Iro, and Aleksandra Fazlipour for assistance with stimuli creation and data collection, and Eleanor Roosevelt High School @ UMD internship program for facilitating UU's involvement. NL was supported by a David Baggett post-baccalaureate fellowship in linguistics.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.neuropsychologia.2016.10.014.

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