

Syntactic Categories as Lexical Features or Syntactic Heads: An MEG Approach

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Are syntactic categories like *noun* and *verb* categories of stems, such that the noun and verb versions of ambiguous stems like *hammer* are distinct, though related, lexical items, or are syntactic categories carried by affixes attached to uncategorized roots, such that noun and verb versions of ambiguous stems are derived forms built on a single root? This paper addresses the representational question posed by syntactic categories by examining the processing of category ambiguous words. If syntactic categories are in fact categories of stems, category ambiguity should yield processing uncertainty parallel to that engendered by other forms of lexical ambiguity, such as homophony. On the other hand, if syntactic categories result from affixation, category ambiguity should yield processing uncertainty parallel to that engendered by syntactic uncertainty, at least if morphological structure reduces to syntactic structure as claimed by Distributed Morphology. A magnetoencephalographic (MEG) experiment exploiting a single word lexical decision task supports the syntactic over the lexical account of syntactic categories; category ambiguity parallels syntactic ambiguity rather than lexical ambiguity. The paper illustrates how neurolinguistic data can contribute to testing competing representational theories, but only when tight linking hypotheses are motivated connecting linguistic theory, cognitive processing, and neural responses.

1 Introduction¹

Somewhat independent strands of research in linguistic theory and in psycholinguistics have converged on a pair of competing hypotheses about the nature of basic lexical categories such as “noun,” “verb,” or “adjective.” With particular precedence in the *Zero Syntax* work of David Pesetsky (1996) and the *Exoskeletal Syntax* work of Hagit Borer (2005), Distributed Morphology (DM; Halle & Marantz 1993) has been exploring the hypothesis that lexical categories are always formed via the affixation of a categorizing morpheme (little *v*, *n*, or *a*) to a syntactically uncategorized root; within linguistic theory, this hypothesis stands in opposition to the more standard approach (as exemplified in Baker 2003) that lexical categories are precisely *categories* of stems that possess no further internal syntactic structure. Within the psycholinguistic literature, well summarized in Vigliocco et al. 2011, the relevant competing positions have been called the *Combinatorial* view, in which the category of a word is not lexically determined but computed via its syntactic environment, and the *Strong Lexicalist* view, in which the syntactic category of a word is a feature of its lexical entry. Connections between linguistic theories of representations and psycholinguistic accounts of memory and processing have evolved to the point that cognitive neuroscience experimentation may inform linguistic theory. In this paper, we present an experiment designed to test whether category determination during word

¹“ We thank Robert Parks for providing the Wordsmyth data used to compute some of our variables for the experimental materials. We additionally thank [omitted to preserve anonymity of the authors].

recognition resembles syntactic processing, as expected on the Distributed Morphology/Combinatorial hypothesis, or resembles the choice between competing lexical entries, as for the resolution of homography, as expected in the Standard/Strong Lexicalist hypothesis.

We present the competing representational claims about lexical categories in (1). The Strong Lexicalist approach shown in (1a) treats syntactic category features as properties of a lexical stem, alongside features associated with the sound and meaning representations of the stem. The Combinatorial/DM approach, illustrated in (1b) with the formalism associated with DM, claims that lexical categories are created via syntactic merger of an uncategorized root with a categorizing affix, which might or might not be pronounced. The key items in the experiment presented here are categorically ambiguous between noun and verb; on the DM view, the roots of these items may be followed by either a little *n* or little *v* suffix, neither of which has a phonological expression for the items chosen for the experiment. We use a single-word lexical decision task methodology with such words to probe category ambiguity without a disambiguating context, exploiting an experimental literature on processing under uncertainty.

No single experiment will decide such an important issue as the representation of syntactic categories, neither within linguistic theory nor within the cognitive neuroscience of language. However, we believe that thinking about the current experiment and its potential implications should at least drive clarification of the competing hypotheses.

Within Distributed Morphology, the hypothesis that all stems of the syntactic categories noun, verb and adjective consist of (at least) a (syntactically) uncategorized root and a categorizing affix pulls together two lines of research. One line concerns the cross-linguistic

distinction between words made from roots via derivational morphology and words made from stems that are already “lexemes” or inflection-ready stems. The work of Arad (2003, 2006) is exemplary here. Verbs made from nouns, for example, exhibit a phonological and semantic transparency with respect to the pronunciation and meaning of the noun, while verbs made from the roots of nouns can show phonological and semantic idiosyncrasies not evident in the corresponding nouns. The second, related, body of work explores the connection between locality constraints on interactions between morphemes within words as compared to constraints on interactions between words in phrases and sentences; here, the presence of a category-determining head independent of a word’s root plays a crucial role in defining locality domains for syntactic, morphological, phonological and semantic interactions. For example, an affix cannot generally trigger contextual allomorphy or contextual allosemy on a root over an intervening category-determining head. Embick and Marantz 2008, Embick 2010, and Marantz 2014 summarize and reference the relevant literature.

For psycho- and neurolinguistic research, the Strong Lexicalist view, as summarized by Vigliocco et al. (2011), is associated with evidence that “grammatical class information is automatically and necessarily retrieved whenever a word is comprehended or produced.” In general, this view motivates and is motivated by research that connects access to the meaning of a word with access to its lexical category. In contrast, the Combinatorial view separates access to those aspects of a word’s meaning carried by the root from the computation of its lexical category. The computation of a lexical category is attributed to the processing of a word in a phrasal context.

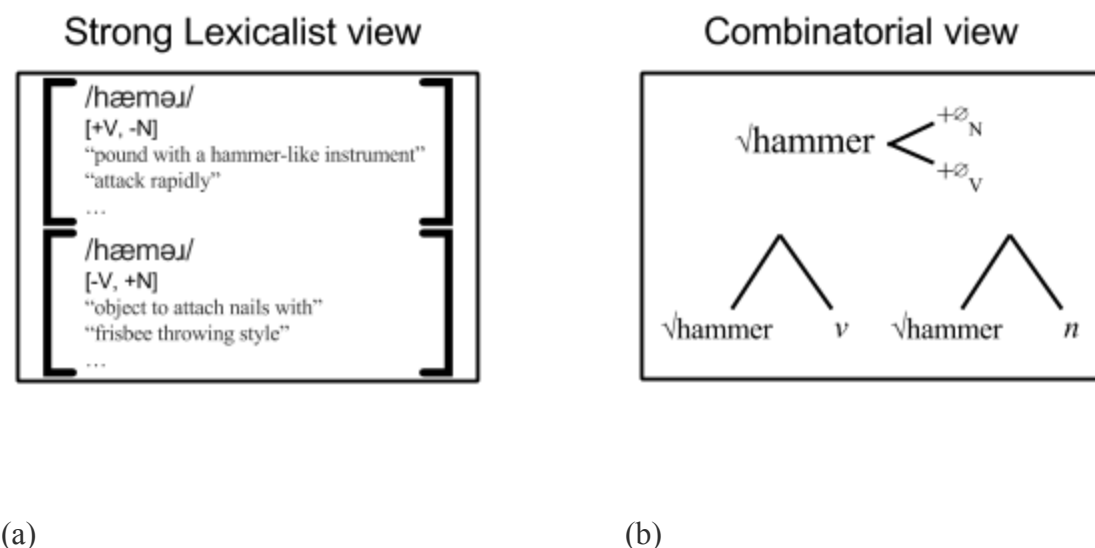


Figure 1

Predictions for experimental results for a single-word lexical decision experiment from the Combinatorial as compared to the Strict Lexicalist view depend strongly on the extent to which syntactic processing is automatically associated with lexical access, even in tasks such as single word lexical decision, where there are no overt task demands for phrasal processing. For DM, the minimal unit of processing for any unit containing a root would be the syntactic constituent containing the root, a category-determining affix, as well as implicated inflectional material; linguistic constituents must be at least the size of a syntactic *phase*, in the sense of Chomsky's *Minimalist Program* (Chomsky, 1995), to be pronounced, interpreted or recognized. Given this consequence of DM, we cannot separate Combinatorial and Strict Lexicalist views by the prediction that the Strong Lexicalist view requires access to lexical category whenever a stem

is recognized while the Combinatorial view does not. For the Strong Lexicalist, the category information is associated with all and any features of the stem that might serve to activate its lexical entry. However, on the Combinatorial view, syntactic projection at least to include a syntactic category head would be required for any task that involves lexical access, necessitating activation of one or more syntactic category nodes in addition to the root. Rather, to separate the predictions of the two views, we must look to the specific predictions that these views make about the process of category assignment, which should be obligatory for stem recognition in both views.

For the current experiment, we exploit properties of the word recognition system that deal with uncertainty. For words (stems) presented visually, the present experiment's crucial stimuli are frequently used either nominally or verbally, leading to syntactic category uncertainty when these words are presented out of context; consider *hammer* (i.e., "He hammers away all day with this heavy hammer."). Uncertainty in language processing works along two dimensions, and there is evidence that processing along these two dimensions in word recognition implicates different brain regions and different time windows relative to stimulus presentation. Along the *paradigmatic* dimension (sometimes conceived as the *vertical* dimension of word choice in a position), there is uncertainty over what root or lexical item is being recognized. For example, in the case of homography, a given visual stimulus like "bank" gives rise to uncertainty along the paradigmatic dimension of whether the word being processed is the river bank "bank" or the monetary bank "bank". Along the *syntagmatic* dimension (sometimes conceived as the *horizontal* dimension of words strung together), there is uncertainty about continuations from a stem to possible suffixes. For one example, in the case of English inflection, a stimulus like

“bank” is consistent with a present tense plural continuation from a verbal stem (“They bank at the Chase around the corner.”) as well as an infinitive continuation (“They want to bank with the Chase around the corner.”). The Strong Lexicalist view treats the noun-verb ambiguity for stems like “hammer” as uncertainty in the paradigmatic dimension, since the noun and verb uses of a stem are distinct, though related, lexical entries, like the two entries for homographs such as “bank.” The Combinatorial view and Distributed Morphology treat the ambiguity as uncertainty in the syntagmatic dimension, like the uncertainty in whether “know” will be followed by a clause (“know that he will leave”) or a noun phrase (“know the answer”).

Our experiment exploits the temporal and spatial precision of magnetoencephalography (MEG) to ask whether the processing of noun-verb ambiguous words elicits brain activity associated with paradigmatic or with syntagmatic uncertainty. Previous MEG work has associated activity in processing visually presented words elicited at anterior areas of the left temporal lobe around 250ms post-stimulus onset (PSO) with syntactic combination and syntagmatic uncertainty, as presented in Section 1.2. Similar research has associated activity at more posterior left temporal regions around 300ms PSO with lexical access and paradigmatic uncertainty. We quantify noun-verb ambiguity for a stem in terms of information entropy (Shannon 1949), where, the higher the entropy, the more equal the probability for the use of the stem as both noun and as verb given corpus observations, while the lower the entropy, the more one of the realizations, either as noun or verb, dominates the probability space. We call this measure Noun/Verb (N/V) entropy. Our competing representational hypotheses about syntactic categories make the following predictions for our MEG experiment: the Combinatorial/Distributed Morphology view predicts that N/V entropy should correlate with

brain activity in the syntagmatic area around 250ms PSO; the Strong Lexicalist view predicts that N/V entropy should correlate with brain activity in paradigmatic regions around 300m PSO. Our experimental design includes variables already associated in the literature with paradigmatic uncertainty, so if we find that N/V entropy correlates with the earlier anterior activity, we should still see in the same experiment modulation of the later, medial activity by these other lexical variables, including homography. That is, the Strong Lexicalist hypothesis would be supported if N/V entropy and homography modulate brain activity in the same spatio-temporal region of response to the ambiguous words. Conversely, the Combinatorial hypothesis would be supported if the N/V entropy and homography modulate brain activity in separable spatio-temporal regions, and if N/V entropy was specifically implicated in regions associated with related combinatorial processes as found in previous studies.

In the next section (1.2) we will review relevant experiments that establish that early left anterior and later left medial temporal activity correlate with syntactic combination and lexical access, respectively. In addition, we will review related cognitive neuroscience experiments on noun-verb ambiguity and its disambiguation. Section 2 presents the experiment designed to test the Combinatorial vs. Strong Lexical hypothesis about syntactic categories; the following Discussion in Section 3 considers a variety of worries about a simple interpretation of the results, which support the predictions of the Combinatorial view. Section 4 concludes.

1.2 Previous Work and its Implications

1.2.1 MEG responses in visual word recognition

Our experiment capitalizes on a long history of research exploiting the single-word visual lexical decision methodology. In this methodology, subjects are presented with a list of letter strings, one string at a time, and for each letter string are asked to press one button if the string is a word, and a different button if the string is not a word. Here, our words and nonwords are presented in random order, so there should be no systematic priming effects from processing one word on the reaction to the next. Experimenters using this paradigm while simultaneously measuring subjects' electromagnetic brain activity via electroencephalography (EEG) or magnetoencephalography (MEG) have identified a series of brain activity peaks or *components* that show sensitivity to different properties of presented words (see Pylkkänen and Marantz 2003 for an overview of these components for MEG). Although there is continuing controversy among psycho- and neurolinguists over the relationship between the observed EEG/MEG components and cognitive models of word recognition, there is growing consensus on the key conclusions that underlie the present experiment. First, early responses (before 200ms post stimulus onset) from occipital and inferior temporal regions are associated with processes recognizing the stimuli as letter strings and identifying the visual word forms of morphemes contained within the string. Generally, semantic variables do not modulate these responses (see Laszlo and Federmeier 2014 for a recent argument that evoked responses before around 300ms are not modulated by the semantic variables typically associated with lexical access). An MEG response from the superior and medial temporal gyri called the M350 in Pylkkänen and Marantz 2003 and the N400m in Vartiainen, Parviainen and Salmelin 2009 has consistently reflected stimulus variables associated with the lexical entry of the stem of a presented word around 300ms PSO; we review the most relevant experiments exploring this response below. Finally,

recent work has identified a response around 250ms PSO², generated in the left anterior temporal lobe, that is modulated by syntactic combination or the anticipation of syntactic combination. In studies that contrast single word presentation with presentation of the same word as part of a two word phrase, more activation at this response is found for the combination condition (Bemis and Pylkkänen 2011 and related papers). In a study directly comparable to the present experiment, which will be discussed in further detail later, Linzen, Pylkkänen and Marantz (2013) found that in a single-word visual lexical decision task, subcategorization frame uncertainty for verb stimuli, quantified as subcategorization frame entropy, also modulated this response.

In interpreting the time course of evoked EEG/MEG responses, we must resist the temptation to conclude that, because evoked response A peaks before evoked response B, processing associated with A happens before processing associated with B, and A feeds B. The fact that we find a correlation with syntactic combination and syntagmatic uncertainty around 250ms while a correlation with lexical access-related variables occurs later should not lead us to conclude that some syntax must be computed prior to lexical access, although these findings would be consistent with such a claim. Nor should we conclude from the fact that lexical variables do not appear to modulate EEG/MEG responses prior to around 300ms in single-word visual lexical decision that lexical access always occurs 300ms after word presentation, or finally, that activation of candidate lexical entries in the brain doesn't occur as soon as any relevant input information is processed. In Fruchter et al. submitted, lexical access for a second, highly predicted word in a two word sequence like “stainless steel” is shown to occur *before* presentation of the second word; that is, in this example, the response that usually occurs around

² Which may or may not contribute to the M250 identified in Marantz and Pylkkänen 2003.

300ms after word presentation occurs after “stainless” but before the onset of “steel”; this response before word presentation is modulated by the frequency of “steel” (independent of the bigram frequency of “stainless steel” in English). In interpreting the results of the experiments to be described below, we concentrate on the relation between stimulus variables and modulations of EEG/MEG responses in single-word lexical decision. Our focus is the relevant responses as identified by their spatio-temporal properties -- brain regions and time windows -- within this particular experimental methodology. What might be the analogous or identical cognitive processes can possibly occur in different time windows relative to stimulus onset given different experimental designs.

In visual word recognition measured by MEG, a series of responses from the occipital cortex (where primary and secondary visual cortices are located) and from the inferior temporal lobe (associated in general with visual object recognition) show sensitivity to properties of the form of a visually presented word. Although the exact cognitive processes reflected in these responses are a subject of current research, there is growing consensus that early responses from the occipital lobe (the visual M100 and the “Type I” response of Tarkiainen et al. 1999) reflect processing of visual features of the input, as well as perhaps recognition of letters as abstract visual objects (e.g., Pylkkänen and Okano 2010). By around 170ms post stimulus onset, a region in the fusiform area of the left inferior temporal lobe, around the area called the “Visual Word Form Area” or VWFA by Cohen and Dehaene (2004), is involved in recognizing the form of morphemes. The M170 response from this area has been correlated with visual morphological decomposition (Solomyak and Marantz 2009, Zweig and Pylkkänen 2009, Lewis, Solomyak and Marantz 2011, and Fruchter, Stockall and Marantz 2013) and the identification of affixes

(Solomyak and Marantz, 2010). Crucially, the responses from this area in this time window are not correlated with *lexical* properties in the technical sense relevant here, as the locus of a connection between form and meaning properties, but only with properties of the orthographic forms of morphemes. In particular, pseudo-affixed words like *brother* show the same effects of decomposition as real affixed words like *farmer* (Lewis, Solomyak and Marantz, 2011), which would be unexpected if this brain response had access to lexical information about *broth* and *brother*. And for word forms with multiple meanings (like *wind* or *bank*; Solomyak and Marantz, 2009, Simon, Lewis and Marantz, 2012), this response is sensitive to the frequency of the form of the word, summing across lexical items and meanings, while the later 300ms response from middle and superior (left) temporal cortices, and not this M170 response, is modulated by the relative frequency of the (competing) meanings for these types of words.

While the early M170 response from the portions of the left inferior temporal lobe is modulated by form properties of the constituent morphemes of a visually presented word, the M350 response (in a time window as early as 300ms PSO in single-word lexical decision tasks) from more superior regions of the temporal lobe has been shown in many studies to be modulated by properties associated with lexical access. As mentioned above, when ambiguous forms (heteronyms or homographs) are presented, the *meaning entropy* (uncertainty about which meaning is intended) modulates this response. For morphologically complex words, the stem frequency (Solomyak and Marantz 2010) and a measure associated with stem access called *derivational family entropy* of the stem modulate this M350 response, while effects of surface frequency (when controlling for stem frequency) are seen later (Fruchter and Marantz, in press).

Two aspects of this M350 response are crucial for the hypotheses tested in the current experiment. First, the modulation of the response by the meaning entropy of ambiguous word forms (*wind*, *bank*) indicates that this response indexes computation associated with paradigmatic uncertainty -- which word did I see, river *bank* or money *bank*? Second, the sensitivity of the response to stem frequency and to derivational family entropy strongly support the claim that the response is an index of lexical access. Derivational family entropy as a property of stems relevant for lexical access requires some explanation. This entropy measure quantifies the probability distribution over derivatives of a stem given the presence of that stem and taking into account both the number of derivatives from the same stem and the relative frequency of the derivatives (including the bare stem, if this is a possible word without further overt affixation). In work devoted to predicting reaction time in, e.g., single-word lexical decision experiments, Moscoso del Prado Martín, Kostić, and Baayen (2004) discovered that a combination of derivational family entropy and surface frequency (the frequency of the actual derived form of a stem presented to the subject) provided a good statistical model, while adding other variables associated with lexical access, e.g., stem frequency, did not significantly improve the model. Fruchter and Marantz (in press) also showed that derivational family entropy significantly modulated the M350 for morphologically complex words as expected for a variable indexing stem access. Moscoso del Prado Martín, Kostić, and Baayen (2004) explain why morphological family entropy might be the key variable associated with lexical access, and there is little doubt that the information going into the computation of this variable is not available without access to the lexical entry of the stem. See the discussion in Fruchter and Marantz for further motivation of this variable as a probe for lexical access.

The argument for considering activity around 250ms PSO in the anterior portions of the temporal lobe as reflecting syntagmatic entropy involves interpreting the results in Linzen, Pylkkänen and Marantz 2013 in the light of MEG work on syntactic combination. Linzen, Pylkkänen and Marantz (2013) examined the effects of uncertainty over syntactic continuations in a single-word lexical decision task. The relevant stimulus variable was entropy over possible subcategorization frames, quantifying uncertainty over syntagmatic continuations from verbs as a function of the number of possible subcategorization frames and their relative frequency. After controlling for “nuisance” variables such as word frequency, subcategorization frame entropy was found to modulate brain activity in the anterior portions of the left temporal lobe around 250ms PSO, in contrast to later M350 effects in more posterior temporal areas. As mentioned above, in a series of studies beginning with Bemis and Pylkkänen 2011, Pylkkänen’s group has identified activity in the left anterior temporal lobe (LATL) as reflecting composition (semantic and/or syntactic) in a time window around 250ms after the presentation of the second word in a two word constituent (like *red boat*). Linzen, Pylkkänen and Marantz 2013 explores the connection between the subcategorization frame entropy result and the literature connecting the LATL to syntactic composition.

1.2.2 Neurolinguistic evidence for category assignment

Several previous neurolinguistic studies have examined the basis of lexical category assignment, but none provide strong clues to the representational question addressed here. The question that has motivated most neurolinguistic research on categories is that of a possible separation in the brain between the location of noun and verb representations and/or a separation in the neural

processing of nouns and verbs in sentence recognition. This question is in principle independent of the representational issue that separates the Combinatorial and Strong Lexical theories, since neither linguistic approach to syntactic categories predicts differential storage for nouns versus verbs. However, if nouns and verbs were somehow stored separately in the brain and processed by different mechanisms, then in single-word lexical decision one might find responses reflecting these differences. Thus the results from experiments exploring potential noun versus verb processing and storage differences might inform the issue of concern here.

Although the literature on noun-verb differences presents a complex picture, with apparently conflicting results, we have not found any results that conflict with our interpretation of the earlier anterior and later medial left temporal MEG responses exploited in the present experiment. Nevertheless, to guard against the possibility that our results might be interpretable as a difference in the representation and processing of nouns versus verbs, we are using as our primary independent variable Noun/Verb (N/V) entropy, which numerically equates items that are mostly used as nouns and items that are mostly used as verbs. What should unite processing of these stimuli is neither noun nor verb specific mechanisms but category uncertainty; correlations with N/V entropy, then, should not be associated with differences in the processing of nouns and verbs, at least not without some theory that might explain why N/V entropy and differential noun versus verb processing should be related.

Previous work on noun-verb ambiguous words can be divided into fMRI studies, which provide possible neural locations for category disambiguation and processing, and MEG studies that give us more specific ideas about the time-course of responses to category ambiguous words. Using fMRI, Tyler, Randall and Stamatakis (2008) presented noun-verb ambiguous

words to subjects as single words, to preserve the ambiguity, and in short phrases that disambiguated the category. The words varied along a continuum of noun dominance, i.e., the frequency of the noun use relative to the verb use. In single word presentation, noun dominance showed no correlation with the fMRI-measured brain responses, arguing against the view that nouns and verbs are stored in different brain areas; on this view, noun dominance should modulate activity in the noun and verb areas, with noun-dominant words showing more activity in noun areas and less in verb areas, and verb-dominant words showing the opposite pattern (see Vigliocco, et al 2011 for further review of the literature supporting the lack of a noun/verb location difference in the absence of syntactic context). However, differences were observed between the noun phrases and verb phrases, i.e., once the ambiguous words were embedded in a disambiguating context. Relevant to the hypotheses being tested here, Tyler, Randall and Stamatakis found more activity for verb phrases than noun phrases in the left posterior middle temporal gyrus, an area included in our region of interest for the MEG response associated with lexical access. Their experiment, then, supports the choice of this ROI as a potential locus for a N/V entropy effect under the Strong Lexicalist hypothesis, since the area is at least involved in processing associated with lexical categories.

Gennari et al. (2007), in another fMRI study looking at disambiguation in context, found an interaction between noun-verb ambiguity and noun or verb context in both the LMTG (left middle temporal gyrus) and LIFG (left inferior frontal gyrus). These results paralleled a very similar fMRI study by Burton et al. (2009), who additionally found correlations with category ambiguity in the LSTG (left-superior temporal gyrus). The LIFG effects are interpreted in terms of control mechanisms that make choices in processing; the medial and superior temporal gyrus

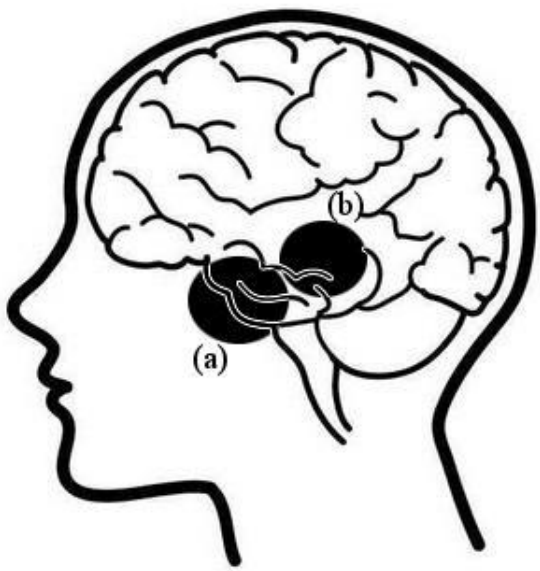
effects for the comparison of the ambiguous and unambiguous words strengthen our decision to examine a middle temporal ROI for a possible N/V entropy effect. In context, then, what we have been calling the left middle temporal region (in contrast to the left anterior temporal region) appears to be involved in processing associated with lexical categories. The fMRI experiments do not speak to the representational issue addressed in this paper, but they do strengthen the motivation for our choice of ROIs.

One of the only published studies on the topic of category ambiguity in MEG was done by Tsigka, et al. (2013), who, like the fMRI researchers, also looked at disambiguation processes with noun-verb ambiguous words in context (in this case, “I dance/*io ballo*” versus “the dance/*il ballo*,” in Italian).³ Among a number of other findings, their experiment showed that activity at intermediate time windows (200-350ms) were greater for verb phrases as opposed to noun phrases. The enhanced activity for verb phrases is consistent with the Tyler, Randall and Stamatakis 2008 fMRI study, and the results are compared to those in Brennan and Pylkkänen 2012, which showed a marginal correlation of brain activity with a word lists versus sentences contrast in ventromedial prefrontal cortex at a similar latency. The results of this study seem compatible with those of the fMRI experiments already reviewed and resonate with MEG studies on syntactic composition.

1.3 Specific Predictions of the Competing Hypotheses

³ See also the important EEG study in Lee and Federmeier 2009; as with the Tsigka et al. paper discussed here, this EEG paper does not speak to computations or responses associated with category uncertainty per se, as opposed to the resolution of category in syntactic context.

The illustration in Figure 2 displays the competing predictions we draw from the Strong Lexicalist and Combinatorial hypotheses on the representation of lexical categories. The Strong Lexicalist position predicts that N/V entropy should modulate activity in the time range of 300ms PSO in the middle temporal regions, associated with lexical access and also implicated in the exploitation of lexical category information by the fMRI studies reviewed above. In contrast, the Combinatorial position predicts that N/V entropy should modulate activity in the time range of 250ms PSO in anterior temporal regions, associated with processing along the syntagmatic dimension. Both hypotheses expect that the variables of derivational family entropy and homographic ambiguity should modulate the 300ms response.

	<p><u>Strong Lexical</u> hypothesis; predicts N/V entropy variable to modulate activity in region (b) <i>after</i> 300ms along with ambiguity (homography) and derivational entropy, as in Simon, Lewis and Marantz 2012, Fruchter and Marantz in press.</p> <p><u>Combinatorial</u> hypothesis; predicts N/V</p>
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	entropy variable to modulate activity in region (a) around 250ms, following Linzen, Pylkkänen and Marantz 2013.
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Figure 2

Along with N/V entropy, we also included a measure of inflectional entropy in our statistical model. N/V entropy is a measure of uncertainty with regard to a particular word's grammatical category. Inflectional entropy is a similar measure of uncertainty to the possible continuations within a word's inflectional paradigm (e.g., for *walk*, as a verb, there is *walk-ing*, *walk-s*, *walk-ed*, *walk-ø*). Once again, the more equal the probability in corpus observations between these continuations and the more such continuations, the higher the entropy.

In our unfiltered corpus data (CELEX; Baayen, Piepenbrock, and Gulikers, 1995), we found that N/V entropy and inflectional entropy are highly correlated. This is expected, since nouns and verbs are associated with different inflectional paradigms. Noun-verb ambiguous items will show up in more inflected forms than unambiguous items, and the higher the N/V entropy, the more equal the frequency over the nominally inflected as compared to the verbally inflected forms. For the purposes of this study, we decorrelated N/V entropy from inflectional entropy in our stimuli set, though we expect both might have independent effects once decorrelated, given past behavioral findings of the effects of inflectional entropy in studies such

as Tabak, Schreuder and Baayen 2005 and Milin, Filipović Đurđević, and Moscoso del Prado Martín 2009. Our focus for this study is on the assignment of category itself using N/V entropy, and thus inflectional entropy here is a “nuisance” variable to control for. Nevertheless, inflectional entropy does reflect uncertainty along the paradigmatic dimension of language, and we might expect it to correlate with activity in our ~200ms left anterior temporal window, in line with Linzen, Pylkkänen and Marantz 2013.

We have stated the predictions of our competing hypotheses in terms of variables “modulating” activity in certain time windows at certain neural regions of interest. We have refrained from predicting the *direction* of the modulation, i.e., whether higher N/V entropy should yield *more* activity or *less* activity at a given ROI. There are two links to the chain of reasoning that would relate the N/V entropy variable to a prediction about the direction of correlation with brain activity. First, we need to specify within a cognitive model whether we expect entropy to result in more or less cognitive computational activity. Then, we need to link computation in the cognitive theory to the magnitude of our brain measure, here an evoked current. The Combinatorial theory of category representation does not come with a specific cognitive theory of the task for category assignment in single word presentation. Uncertainty about category assignment might lead to delay in committing computational resources to combining a stem with a categorical affix, yielding less activity with higher entropy. Linzen, Pylkkänen and Marantz (2013), who observed lower activity with higher subcategorization frame entropy in single verb recognition, offer this as one possible explanation. On the other hand, category uncertainty might yield competition between the possible category affixes, with higher entropy resulting in greater activity. The present study includes no stimulus manipulations that

we think will help develop the theory of the task for category assignment in single word presentation of ambiguous items; therefore, we will refrain from specifying predictions about the directionality of any observed correlations with entropy measures here. Similar remarks apply to predictions for our lexical access variables of derivational family entropy and homographic ambiguity. In the Discussion, we will note the direction of any significant correlations between the stimulus variables and our brain responses and indicate the correspondence between our findings and similar results in the literature. We will leave to further investigation the development of cognitive models of processing that would make precise predictions for the directionality of the measured correlations.

2 Experiment

2.1 Methods

2.1.1 Participants

13 (9 female) right-handed (assessed using the Edinburgh Handedness Inventory; Oldfield, 1971) native English-speakers with normal vision participated in this experiment (age range).

Participants gave informed consent and were paid for their time. One participant was excluded due to excessive MEG sensor noise during data collection. Human participants' approval was obtained from both the NYU Abu Dhabi (United Arab Emirates) and NYU (United States) Institutional Review Boards.

2.1.2 Stimuli & Design

The stimuli consist of 313 English words and 319 English-pronounceable nonwords; the number of nonwords was selected to provide an even number within 8 experimental blocks given the number of words. The stimulus words were selected from the CELEX corpus (Baayen, Piepenbrock and Gulikers, 1995), with the criteria of being monomorphemic, monosyllabic, and with no overt derivational or inflectional affixation. Words ranged from 2 to 7 characters in length, and were selected to minimize the correlations among a range of lexical variables, described in detail below. Words were excluded if they had potential syntactic categories other than a noun or verb (e.g., *smart*), if participants' average accuracy in recognizing the word in a lexical decision task was lower than 85% according to the English Lexicon Project (Balota et al. 2007), or if they were irregular past forms (e.g., *did*). Nonwords matched to the words were created using Wuggy (Keuleers and Brysbaert, 2010).

2.1.3 Ambiguity-related predictors

Two types of semantic ambiguity are distinguished in the literature: homographs are ambiguous between multiple unrelated meanings (e.g., *bank* can mean “river bank” or “financial institution”), whereas polysemous words have multiple related senses (e.g., *chicken* can refer to either the animal or its flesh). Those two types of ambiguity differ in their effects on word recognition (for discussion, see Simon, Lewis, and Marantz 2012).

Number of senses was estimated as the number of “synsets” (synonym sets) associated with the word in WordNet, summed across all parts of speech and meanings (Miller, 1995; Baayen,

Feldman and Schreuder, 2006). Some of the senses of the word *chicken*, for example, are “a domestic fowl”, “flesh of a chicken” and “a person who lacks confidence”. **Number of meanings** was obtained from the Wordsmyth Online Dictionary (Parks, Kennedy, and Broquist 1998).

2.1.4 Morphological predictors

The three syntagmatic predictors quantify the uncertainty in various probability distributions over words that are morphologically related to the word being recognized (Moscoso del Prado Martín, Kostić, and Baayen 2004). The Shannon entropy of a probability distribution is the expected information in an outcome:

$$H(X) = - \sum_x P(X = x) \log_2(P(X = x))$$

The frequency counts and morphological parses used to construct these probability distributions were based on the CELEX corpus (Baayen and Piepenbrock 1995). We used add-one smoothing to deal with sparse data (Jurafsky and Martin 2008). For example, if a word occurs twice as a noun and zero times as a verb, we would not want to conclude that its verb probability is exactly zero. For a word that occurred f_n times as a noun and f_v times as a verb, then, the noun probability was estimated as $(f_n + 1)/(f_n + f_v + 2)$, and the verb probability as $(f_v + 1)/(f_n + f_v + 2)$. **Noun/Verb:** The probability that the bare stem being recognized (e.g., *ache*) is a noun or a verb. For example, if the probability of one of the categories is 0.25 and the probability of the other is 0.75, then the noun/verb entropy will be as follows:

$$-0.75 \log_2(0.75) - 0.25 \log_2(0.25) = 0.81$$

Inflectional family: Inflected forms of the stem being recognized, excluding the bare form.

Syncretic forms were counted separately. For the stem *ache*, for example, the distribution consisted of the following forms: *aches* (plural noun), *aches* (third person singular, present), *aching* (participle), *ached* (past tense), *ached* (participle). The bare form was excluded since it was used to calculate Noun/Verb entropy, and including it in the calculation of inflectional entropy would introduce high correlation between the two variables.

Right derivational family: The distribution of all words that are formed from the stem by combining it with one or more non-inflectional morphemes (Moscoso del Prado Martín, Kostić, and Baayen 2004). In a departure from previous work, only those family members in which the recognized form is the leftmost morpheme were considered; for the word *sleep*, for example, *sleep* and *sleepwalk* were included, but *oversleep* was not. Multiword lemmas such as *sleep in* were likewise not considered to be part of the morphological family, despite being tagged as such in CELEX.

2.1.5 Control variables

Word Frequency: Obtained from the SUBTLEX database (Brysbaert and New, 2009).

Orthographic Neighborhood Size: The number of words that can be produced by changing a single letter in the word in question (*Coltheart's N*: Coltheart et al. 1977); obtained from the English Lexicon Project (Balota et al. 2007).

2.1.6 Correlations

	Infl	Freq	Deriv	Neighbor	Senses	Homogr	N/V
Infl							
Freq	0.01						
Deriv	0.1	0.02					
Neighbor	-0.01	0.25	0.1				
Senses	0.12	0.52	0.09	0.09			
Homogr	-0.08	0.04	0.09	0.3	0.1		
N/V	0.12	-0.15	0.27	-0.09	0.08	-0.04	

Table 1: Correlations between stimulus variables (Pearson's r). Infl = inflectional family entropy; Freq = log-transformed word frequency; Deriv = right derivational family entropy; Neighbor = neighborhood size (Coltheart's N); Senses = number of senses; Homogr = is the word a homograph? (a binary predictor); N/V = noun/verb entropy.

2.2 Procedure

The experiment was conducted at the NYU Abu Dhabi Neuroscience of Language Lab in the United Arab Emirates. Participants performed lexical decision task on visually presented words while neural data was recorded using a 208-channel axial gradiometer MEG system (Kanazawa Institute of Technology, Kanazawa, Japan), with a sampling frequency of 1000 Hz. Before running the experiment in the magnetically shielded room (MSR), we digitized the head shape and three fiducial points (nasion, left and right preauricular) of each participant for purposes of source localization and co-registration with an averaged MRI brain (*fsaverage*, Martinos Center),

in lieu of individual participant structural MRIs. We placed five marker coils on the participant's head that served to provide its position while in the MEG helmet. Two recordings of head position from the marker coils were taken, one before and one after running the experiment itself. These two snapshots were then averaged to approximate any overall positional error due to movement during the experiment.

Stimulus presentation was done on an Apple Mac mini system running OS X Snow Leopard with PsychToolBox (Brainard 1997; Pelli 1997) using an NEC NP-350W projector, with a screen ~85 centimeters away from the participant's head. Stimuli were presented using a white 30-point Courier font on a black background. Responses were indicated with the left hand, using the middle finger to indicate nonwords and the index finger to indicate words. Each trial began with a fixation cross (+) that appeared for 300ms followed by a blank screen for 300ms before stimulus presentation. The stimulus remained on the screen until the participant responded. A short practice was conducted before the actual experiment. The inter-trial interval was randomized between 350ms and 650ms for each trial. Stimuli were presented in pseudorandom order consisting of 8 blocks of 79 trials per block. No feedback was given after the practice phase of the experiment.

2.3 Data Processing

2.3.1 Source Space Processing

Preprocessing of MEG data began with the MEG160 software package (Yokogawa Electric Corporation and Eagle Technology Corporation, Tokyo, Japan), removing any bad channels by

averaging together the surrounding channels. Noise reduction was applied using the Continuously Adjusted Least-Squares Method (CALM; Adachi et al. 2001). All data were low-pass filtered at 40Hz. By-subject coregistration and scaling with averaged MRI brain from the Freesurfer software package (CorTech Labs, La Jolla, CA and MGH/HMS/MIT Athinoula A. Martinos Center for Biomedical Imaging, Charleston, MA), and conversion of files to fiff format was achieved using the MNE-Python suite (Gramfort et al. 2013). Each averaged MRI brain was scaled to the participants' head shape as digitized before the experiment. Source space analysis was conducted using these scaled average brains. From this point on, all procedures from Solomyak and Marantz 2009 were followed.

The MNE software package (Gramfort et al. 2014) was used to create a source space of 5,124 sources per hemisphere based on the scaled average-MRIs for each participant. The boundary-element model derived from each MRI was then used to generate the forward solution, which estimates the magnetic field measurements at the sensors from each current source. The forward solution was utilized in the calculation of the inverse solution, necessary for estimating the distribution of magnetic activity over time and in space. All minimum norm estimates were signed (positive/negative) given the directionality of the current estimations, using a free orientation methodology (Fruchter and Marantz (in press) provide technical details of and reasoning behind these choices). There were two different but related uses of the inverse solution. First, we estimate activity measured across words, averaged across participants and saved using the dynamic Statistical Parameter Mapping method (*dSPM*; Dale et al. 2000) to represent activity for the purpose of creating functional Regions of Interest (functional ROIs). Second, the inverse solution was employed for every experimental trial, extracting data only

averaged only within functional ROIs themselves; these data were saved and later used in linear mixed-effects regression models.

2.3.2 Functional ROI Analysis

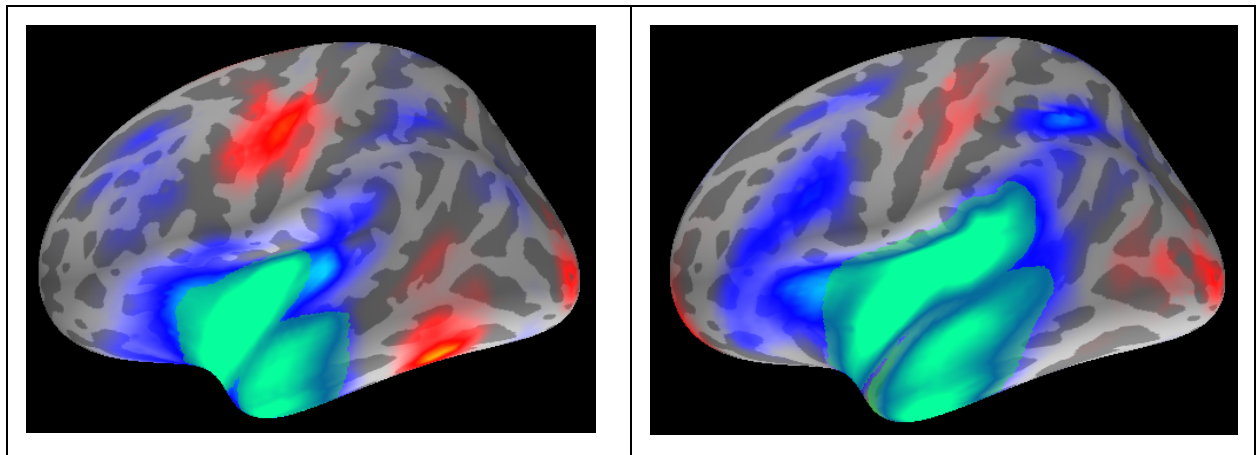


Figure 3: functionally-defined ROIs in green; left covering the peak left temporal activity at 217ms PSO, right covering the peak activity at 292ms PSO

For the purposes of statistical analysis, we used regions based on the visualization of averaged peak activity for words, from the left temporal lobe. Data from each individual's scaled MRI was morphed onto the averaged inflated brain provided by FreeSurfer. These data were calculated as dSPM values, and then these values were grand averaged across participants. There were two major peaks between 150-350ms, our time window of interest given previous studies: an anterior peak at 217ms PSO and a more widely distributed peak at 292ms.

ROIs for analysis were functionally defined, based on these peaks in the left temporal region, using the standard inflated cortical surface. These regions were selected by the visual representation of the peaks. Each peak had two distinct spatial components, one more posterior

on the lateral surface than the other; these were considered the same ROI because of the lack of structural MRIs, which makes higher resolution localization difficult, resulting in the smearing of activity across participants. Lastly, the ROIs were morphed back onto each participant's respective scaled *fsaverage* MRI and the inverse solution was calculated for each trial, using the specific participant's morphed ROI.

From these data, a single-trial analysis was performed using linear mixed effects models (Bates, et al. 2013); for each trial from each participant, the activity from the relevant ROI was averaged across a 50ms time window centered on the ROI's associated grand average peak, as seen above. Our model utilized the following predictors: N/V entropy, number of senses, inflectional entropy, word frequency (surface), ambiguity (as a binary value -- homographic or not) and derivational entropy. We included random effects for participant and item, using random slopes by subject for N/V entropy and inflectional entropy. More complex random effects structures were not used because of model convergence issues.

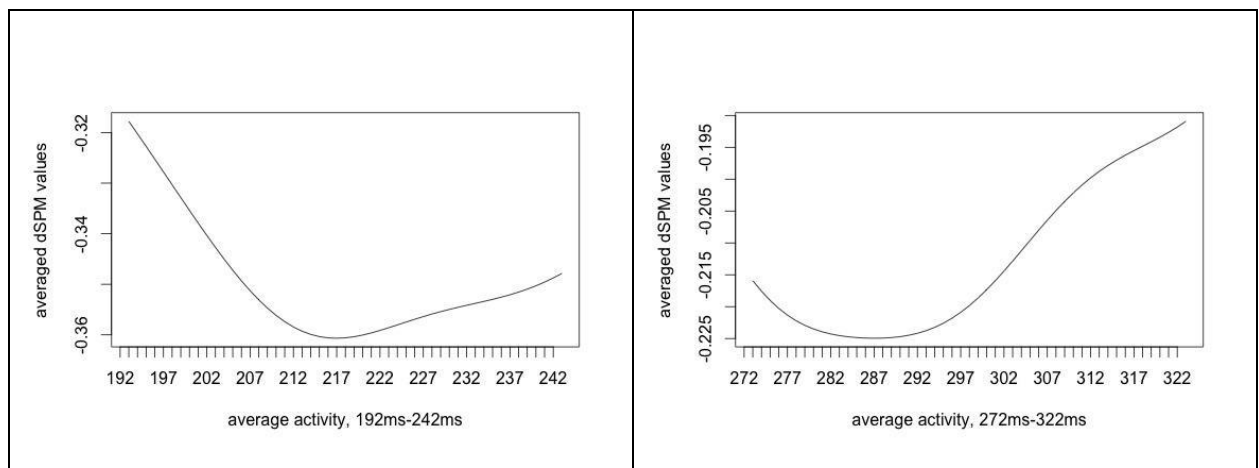


Figure 4: averaged activity within functional ROIs, showing negative peaks

2.4 Results

2.4.1 Behavioral

Predictor	Estimate	Std. Error	t-value	p-value
N/V Entropy	-0.057	0.026	-2.18	0.031 *
Inflectional Entropy	-0.015	0.03	-0.52	0.604
Word Frequency	-0.018	0.004	-4.40	> 0.001 *
Derivational Entropy	-0.008	0.011	-0.76	0.448
Number of Senses	-0.005	0.008	-0.65	0.517
Ambiguity	0.002	0.011	0.20	0.81

Table 2: Behavioral results

Overall accuracy was 0.98. All incorrect trials and trials with reactions times outside of two times the standard deviation of the mean were removed, reducing an original data set of 3756 trials to 3629 trials. By-participant mean reaction times ranged from 570ms to 1070ms; mean reaction time across participants was 755ms, and the median was 684ms.

N/V entropy had a significant effect on reaction times -- higher entropy was associated with faster responses ($\beta = -0.58$, $p = 0.031$). Frequency had a more significant effect on reaction times in all trials ($\beta = -0.018$, $p < 0.001$); frequent words were recognized faster. None of the other predictors had a significant effect on reaction times.

2.4.1 MEG

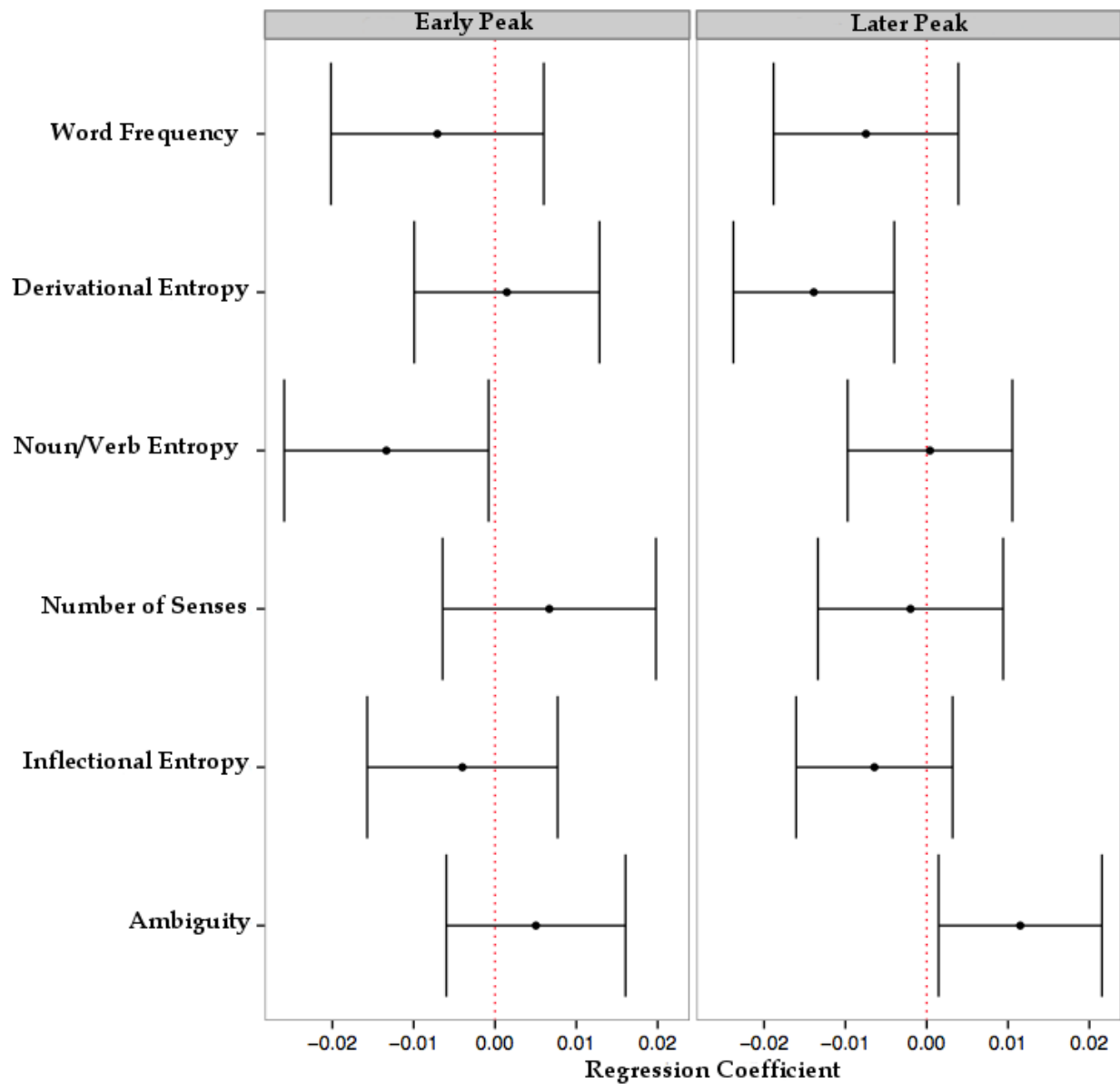


Figure 5: effects of stimulus variables on brain responses at functional ROIs; regression coefficients with 95% confidence intervals

Figure 5 presents linear mixed effects regression models fitted to the Early 217ms Peak ROI, and to the Later 292ms Peak ROI, one model for each ROI. The only significant predictor

for activity in the Early Peak ROI is N/V entropy. Ambiguity and derivational entropy are both significant predictors of activity in the Later Peak ROI.

2.4.1.1 Early Peak

Predictor	Estimate	Std. Error	t-value	p-value
N/V Entropy	-0.013	0.006	-2.13	0.039 *
Inflectional Entropy	-0.004	0.005	-0.68	0.48
Word Frequency	-0.007	0.006	-1.08	0.27
Derivational Entropy	0.001	0.005	0.26	0.8
Number of Senses	0.006	0.006	1.02	0.3
Ambiguity	0.005	0.005	0.91	0.36

Table 2: linear mixed effects model of early response peak

The early, anteriorly-focused peak centered on 217ms showed a correlation with N/V entropy ($\beta = -0.01332$, $p = 0.04$) and no significant correlation with inflectional entropy. The negative beta value here means more negatively-signed activity for higher-N/V entropy words; that is, the more ambiguous the words, the more activity in this ROI.

2.4.1.2 Later Peak

Predictor	Estimate	Std. Error	t-value	p-value
-----------	----------	------------	---------	---------

N/V Entropy	-0.0004	0.005	0.08	0.88
Inflectional Entropy	-0.001	0.004	-1.34	0.18
Word Frequency	-0.007	-0.007	-1.31	0.19
Derivational Entropy	-0.0138	0.0049	-2.81	0.005 *
Number of Senses	-0.001	0.005	-0.35	0.73
Ambiguity	0.011	0.005	2.29	0.031 *

Table 3: linear mixed effects model of later response peak

The later, laterally-distributed peak centered on 297ms showed correlation with derivational entropy ($\beta = 0.014$, $p = 0.005$) and with ambiguity ($\beta = -0.011$, $p = 0.022$). There was no effect of N/V entropy or number of senses. The positive regression coefficient for the derivational entropy variable means that there was less (negative) activity for the words with higher entropy -- more derived words and/or a more even distribution of frequencies across the derivative. The negative beta for the homographic ambiguity variable means that there was less (negative) activity for the words with more than one meaning as compared to the words with one meaning.

2.4.2 t-maps

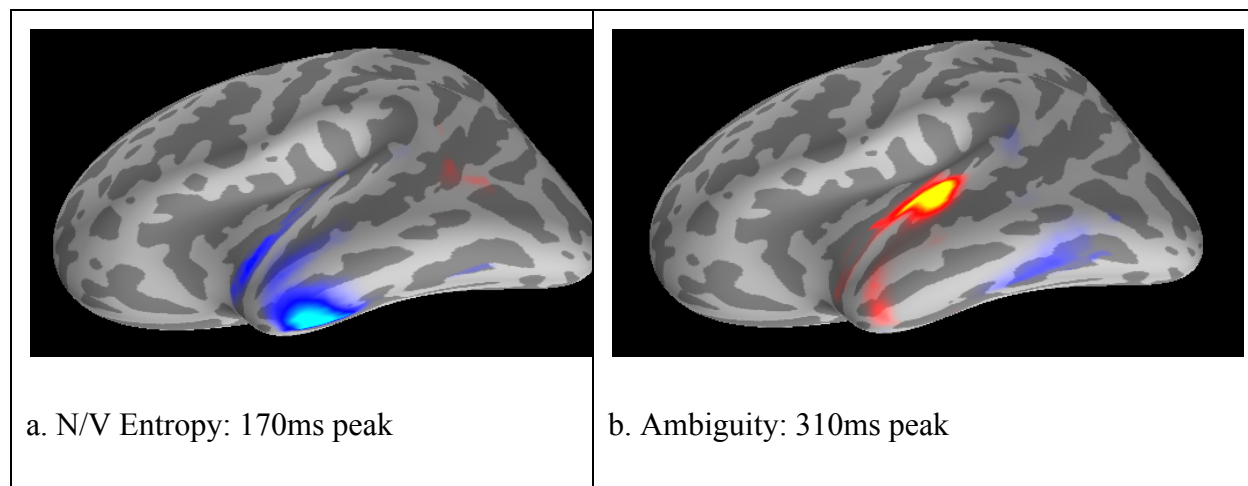


Figure 6: “t-maps” of uncorrected $p < .05$ correlations with predictors (view: underside of left temporal lobe)

Since our functionally defined ROIs cover much of the left temporal lobe and largely overlap, the ROI analysis itself does not yet completely conform to the assumption behind our competing hypotheses that the early syntagmatically related activity is located more anterior than the later paradigmatically related activity. We performed an additional analysis to more precisely identify the location of the correlations between our critical variables and the left temporal activity in our two time windows. This analysis asks, where in the left temporal lobe and at what latency post stimulus onset are the correlations with N/V entropy and with homographic ambiguity most prominent? The maps in Figure 6 are plots of t-values greater than ± 2 (positive t-values are red, negative are blue) for the correlations between brain activity and our variables across subjects; the greater the absolute value of the t-value, the brighter the graphical representation on the brain. The maps show the distribution of t-values at the peak latency for these t-values over time. The N/V variable’s t-values below -2 (conforming to the negative correlation between N/V entropy and brain activity in our large ROI) are concentrated in the anterior part of the left

temporal lobe, peaking at around 170ms, while the ambiguity variable's t-values above 2 (conforming to the positive correlation between ambiguity and brain activity) are concentrated in more posterior regions, peaking at around 310ms.

The t-maps were calculated by taking dSPM-based activity across trials in each subject, looking over a time window from stimulus onset to 400ms PSO, and regressing the activity at each source point, for each subject, with the variable of interest over trials. This resulted in a three dimensional array (participant * time * space) mapping regression values for predictors of activity onto cortical source locations. These values were then used in t-tests across subjects at each spatio-temporal point, asking whether distribution of regression coefficients across subjects was significantly different from one centered on zero. The t-values replaced the regression values, giving one uncorrected map of t-values, distributed across space and time.

Because the t-values in our t-maps are uncorrected for multiple comparisons across space and time, Figure 6 by itself should not be taken as the result supporting the Combinatorial over the Lexical view of categories. The main result of the experiment is captured by the ROI analysis, involving large ROIs over the left temporal lobe; given the statistical significance of the correlations between our variables and the two ROIs, the t-maps help more precisely identify the location of the significant correlations.

3 Discussion

Given the predictions illustrated in Figure 2, the results of this experiment support the Combinatorial/DM view over the Strong Lexical view of syntactic category representations. As predicted by the Combinatorial view, N/V entropy modulated earlier, left anterior temporal

activity, while variables associated with lexical access modulated later, more posterior temporal activity. This pattern of results suggests that syntactic category is assigned independently from other variables associated with specific word meaning or lexical access as seen in Simon, Lewis and Marantz 2012, and Fruchter and Marantz in press. Our methodology for identifying spatial ROIs in the brain corresponding to earlier and later activity yielded quite large anatomical areas that greatly overlapped. However, a subsequent t-map analysis clearly located the hotspot for the identified early N/V entropy effect to anterior areas and for the later homographic ambiguity effect to distinct more posterior areas, confirming the identification of the location of the two effects from this experiment with location of the relevant effects from the previous literature.

Readers of the psycholinguistic literature unfamiliar with recent evoked response work in MEG and ERPs may be somewhat surprised by the apparent discrepancy between the behavioral results and MEG results presented here. As in other lexical decision experiments, we find that word frequency is overwhelmingly the most significant factor predicting RT; the two evoked brain responses, on the other hand, are not modulated by word frequency when factors like derivational entropy are controlled for. Yet this discrepancy is common in studies of visual word recognition, in particular of morphologically complex words, where surface frequency of the morphologically complex form is the best predictor of reaction times while not modulating brain responses around 300ms POS (see Fruchter and Marantz in press). Cognitive models of word recognition should explain why whole word frequency matters most for pushing the button in lexical decision, while other variables dominate brain responses associated with lexical access (see Fruchter and Marantz in press for a discussion related to Taft's 1979 model of

morphological processing). Our finding that N/V entropy facilitates RT in lexical decision, with higher entropy leading to faster reaction times, should add to the data relevant to these models.

In our introduction, we emphasized that previous neurolinguistic literature on lexical categories has concentrated on possible differences in the localization of noun and verb storage, as well as possible processing differences between nouns and verbs. By employing N/V entropy as our variable of interest to index category uncertainty, we hoped to avoid effects associated with the noun-verb difference; words that are strongly either nouns or verbs have equal N/V entropy values. Nevertheless, we did want to investigate whether the items in our experiment were somehow chosen in a way such that our N/V entropy effect might be attributable, instead, to a category-specific response. Following Tyler, Randall, and Stamatakis 2008, we reason that noun dominance, a measure of the skew in probability for N/V ambiguous items toward the noun end, might explain our data as well as N/V entropy; this might be true if our correlations with N/V entropy were dominated by the difference, e.g., between high and low entropy items among the highly noun dominant stimuli, with the verb dominant items just adding noise to the model. Recall, however, that Tyler, Randall, and Stamatakis did not find a noun dominance effect for ambiguous items presented out of disambiguating context, but they do explain why this variable is key to this issue.

We defined noun dominance as the log of the estimated probability that the word is used as a noun (see section 2.1.1 for detail).⁴ Since noun dominance and N/V entropy are calculated

⁴ Note that we could have called the variable “verb dominance,” since the noun and verb fractions of the total word frequencies for our stimuli are reciprocal; nothing in this exploration of an alternative account of our results depends on nouniness being special as opposed to verbiness

from the same source, they cannot serve as predictors in the same model; we thus looked at two different models. Behaviorally, across the two different models we find an effect for both N/V entropy ($\beta = -0.57$, $p = 0.031$), and noun dominance ($\beta = -0.05$, $p = 0.01$), and for word frequency in both ($\beta = -0.018$, $p < 0.001$ and $\beta = -0.015$, $p < 0.001$, respectively, for the two models). We may conclude from Sereno 1999 that nouns have a facilitatory effect on reaction times in lexical decision as compared to verbs, leading us to expect the observed facilitatory effect of noun dominance on RT.

In the neural data, for a model replacing N/V entropy with noun dominance, neither of our two ROIs show a significant effect of noun dominance, for the earlier, anterior response ($\beta = -0.01$, $p = 0.092$), and for the later, posterior response ($\beta = -0.005$, $p = 0.45$). Thus we may tentatively reject the most obvious alternative hypothesis to explain our data -- that our N/V entropy effect reflects a differential response to nouns vs. verbs rather than syntactic category uncertainty.

Although we were careful to formulate our hypotheses in terms of variables *modulating* brain activity rather than *increasing* or *decreasing* brain activity, the observed directionality of our effects deserve some comment. The early effect of N/V entropy is such that the higher the entropy, the more the activity. This directionality contrasts with that observed in Linzen, Pylkkänen and Marantz 2013 for subcategorization frame entropy, where higher entropy yielded less activity. Taking this contrast at face value, one might speculate about how these differences relate to task differences between the experiments. For example, in the case of category ambiguity, the competing, phonologically null, “continuations” from the root are presented with the root, while in the case of subcategorization frame entropy for verbs presented in isolation, the

competing syntactic continuations are never presented. In one case, the processing system might be committing resources toward resolving the competition, and in the other case not.⁵ We will refrain from such speculation here, reemphasizing the point made in the introduction that our cognitive models need to be refined to make precise predictions about the directionality of these effects given particular experimental tasks.

The later effects of derivational entropy and of homographic ambiguity go in different directions; higher derivational entropy yields more activity and ambiguity yields less activity. Although these directions are apparently in conflict with the directions of similar effects for single-word lexical decision in some of the literature, the stimulus sets across experiments differ enough that comparisons are difficult, and absent a strong hypothesis about directionality from a motivated cognitive theory given the stimulus list, we cannot conclude much from these discrepancies. For example, Fruchter and Marantz (in press) find that derivational entropy reduces the activity for the M350 type response we've identified as our later, lexical access indicator, while we find that derivational entropy increases our later response. The most striking difference between the materials in the two experiments is that Fruchter and Marantz used words with overt derivational suffixes, while our items are uniformly simple stems (with respect to overt morphology). In addition, Solomyak and Marantz (2011) found that stem frequency for morphologically complex words, like our derivational entropy variable, increased the amplitude of the M350, where stem frequency correlated with derivational entropy for that stimulus set.

⁵ It is also noteworthy that the finding in Linzen, Pykkänen and Marantz 2013 is based on averaged positively-signed activity, contrasting with the averaged negatively-signed activity in our data. The sign on the activity here reflects the direction of the current dipoles with respect to the head, and the difference in sign might reflect distinct neural generators or differences in the methods used to define the spatial ROIs.

The directionality of the effect for our homographic ambiguity variable is also opposite what we might expect given previous findings. In our study homographic words predict less activity at the M350 while Simon, Lewis and Marantz (2012) found increased given greater entropy among meanings (a variable computed over numbers of meanings and their relative frequencies). There are potential differences between our binary homographic ambiguity measure and the meaning entropy measure of Simon et al. but the most striking difference between the experiments is in the constitution of the stimulus set. Simon, Lewis, and Marantz chose items to span the range of meaning entropy, while our items were chosen to cover a range of N/V entropy while decorrelating N/V entropy and inflectional entropy. To investigate whether our findings are really in conflict with Simon, Lewis, and Marantz, we would need a stimulus set that provided appropriate variation along the dimensions associated with the crucial variables in both experiments.

4 Conclusion

The experiment presented in this Remark provides evidence for the Distributed Morphology/Combinatorial view on the representation of lexical categories over the Lexicalist view by linking the N/V ambiguity to syntagmatic uncertainty for DM and to paradigmatic uncertainty for the Lexicalists. If we have correctly associated the ~250ms anterior temporal response with syntagmatic uncertainty and the ~300ms medial temporal response with paradigmatic uncertainty, then the correlation of N/V entropy with anterior temporal activity around 250ms PSO argues for the DM position over the Lexicalist position.

A natural response from a supporter of the Lexicalist view would be to propose that the early N/V entropy response reflects early access to category features of lexical items to be used to predict or project syntactic structure. The question raised by such a proposal is why the relative frequency of two related lexical items, the noun and verb entries for the ambiguous forms, should systematically modulate activity associated with the computation of syntactic structure. Likely, the Lexicalist would want to show that, for the items used in our experiment, N/V entropy correlates with some other variable associated with the items, and this variable fits with an account of lexical access that relates uncertainty on the paradigmatic dimension (is it the noun or the verb lexical item?) to processing of syntactic structure. Such a line of reasoning would productively lead to further experiments pitting the N/V entropy variable against this new variable, while furthering our understanding of the connection between linguistic representations and neural-cognitive processing.

On the other hand, these results do not let the DM theorist rest easy, either. We exploited the landscape of existing neurolinguistic experiments to derive competing hypotheses from the DM and Lexicalist views for a very particular set of stimuli -- not-overtly-inflected noun-verb ambiguous stems -- under minimal assumptions about the relationship between linguistic representations and language processing in visual word recognition. Given that syntactic category assignment is a type of syntactic processing, identical to processing derived words with overt affixes, a number of questions arise about the computations involved in the present experiment and for types of stimuli not used here. For example, is the N/V ambiguity resolved in single-word lexical decision, and if so, in what time frame and via what computations? The items employed here should evoke paradigmatic uncertainty with respect to the inflectional

morphology that follows the null category suffix; how should this inflectional entropy be computed by the linguist, and where and when do we expect to find such inflectional entropy effects, given that inflection depends on the syntactic category of the stem? What do we expect for the 250ms anterior temporal response in situations in which we have a bound root and an overt category suffix comparable to the null category suffixes exploited here, e.g., in *toler-ate*? What do we expect when the category is restricted by prior context (“to hammer” vs. “the hammer”) or by an overt inflectional suffix (“hammered”), the way such ambiguous items have been presented in previous neurolinguistic experiments discussed in Section 1.2? Developing answers to these questions will further cement the ties between the linguistic theory of linguistic representations, the cognitive theory of language processing, and the neurolinguistic theory of the neural bases of language, expanding the empirical consequences of hypotheses from any of these theories.

In his book on lexical categories, Mark Baker endorses what we have characterized as a Lexicalist view, but explains the way that the types of data he presents could be explained within a Combinatorial framework, where the differences between the frameworks “could largely collapse” (Baker 2003, fn 2; pp 269). Within a general Chomskyan approach to linguistics, where the object of study is the Faculty of Language underlying everything a speaker/listener does with language, the difference between a Combinatorial and Lexicalist view of syntactic categories should be huge, not “very narrow” as Baker claims (ibid). While DM-oriented linguists have drawn empirical consequences from this difference for standard linguistic data (see Embick and Marantz 2008, Embick 2010, and Marantz 2014), here we emphasize that these different linguistic claims hold large implications for language processing, given a sharp

distinction in general between syntagmatic and paradigmatic uncertainty and decisions in language use. Enlarging our perspective on the data relevant to proposals in linguistic theory helps to amplify the significance of representational claims and clarify the commitments associated with theoretical apparatus like features and tree structures.

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