Neuromagnetic evidence that differences in noun and verb processing are modulated by the presence of a syntactic context

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Abstract

We investigated the hypothesis that differences in the processing of verbs and nouns are modulated by the presence or absence of a syntactic context. When presented in isolation, no word category differences were observed over the left hemisphere. Verbs elicited slightly stronger magnetic fields than nouns over the right hemisphere. When presented in a minimal syntactic context, nouns elicited stronger fields than verbs over left posterior temporal regions (as indicated by root mean square signals and brain surface current density maps). Analysis of BSCD maps also indicated that verbs in context elicit stronger responses than nouns over left anterior regions.

1 Introduction

It is generally accepted that open class words (such as nouns and verbs) and function words are represented differently in the brain [1,2]. However, there is a long-standing debate in cognitive neuroscience about the existence of differences in the cortical representation of words of different categories within the open class, especially with respect to verbs vs. nouns. Several previous studies have investigated this issue by examining neurological patients with language deficits [3], or by using imaging techniques such as ERPs [4], PET, or fMRI [5]. The results of these studies are relatively heterogeneous and have so far failed to yield a consistent pattern of differences between verbs and nouns.

In the present study, we investigated the hypothesis that the effects of word category might be more pronounced in syntactic contexts, i.e., when the word's category plays a critical role for the analysis of the grammatical relations among the perceived words [6]. To this end, we measured event-related neuromagnetic fields while participants listened to verbs and nouns which were either presented in isolation or in a minimal syntactic context consisting of one word.

2 Methods

2.1 Participants

Altogether, fifteen volunteers (8 females, 20 to 29 years) participated in the study after giving informed consent. All participants were right-handed native speakers of German without known psychiatric or neurological disorders. For a subset of six participants (2 females) anatomical MRI data sets were available. For these subjects, source modeling was performed.

2.2 Material

Word stimuli were either verbs or nouns. Verbs were inflected (third person), half of them in plural (e.g., 'lachen'/' laugh') and the other half in the third person singular (e.g., 'geht'/'walks'). Nouns contained both singular nouns ending with 't' (i.e., with the same ending as the singular verbs used in the present study; e.g., 'Draht'/'wire') and plural nouns with '-en' ending (i.e., with the same ending as the plural verbs in German; 'Nasen'/'noses'). These specific instances of verbs and nouns were selected in order to control as good as possible for the surface characteristics of the words. There were four different stimulus conditions in the present study:

(1) nouns, without context
(2) verbs, without context
(3) nouns, with context
(4) verbs, with context

Syntactic contexts were formed by adding one single word to the stimuli, namely either a pronoun for verbs ('er geht'/'he goes' and 'sie lachen'/'they laugh') or an article for nouns ('der Draht'/'the wire' and 'die Nasen'/'the noses').

128 stimuli per condition were presented. Across conditions, items were matched for frequency of occurrence and word length (i.e., number of letters and syllables).

2.3 Experimental Paradigm

Stimulus words were spoken by a trained female speaker, recorded, digitized, and presented from a computer during the experiment. The words of the four expermental conditions were presented in a pseu-

dorandomly ordered sequence via plastic tubes. 750 ms after the offset of the stimulus word, participants were cued visually as to the response key assignment for a word category judgment task. The subsequent word was presented after an ISI of 1300 to 1700 ms after the response.
The experiment was run in four separate blocks. Half of the subjects listened to the blocks with verbs and nouns without context first, whereas the other half first was presented with words in context.

2.4 MEG Recording and Analysis

Neuromagnetic fields elicited during the experiment were measured continuously with a sampling rate of 508.63 Hz and a passband from DC to 100 Hz using a 148 channel whole-head WH Magnes 2500 system (4D-NeuroImaging). In addition, electro-oculogram was recorded in order to control for artifacts. Before and after each block, the head position was determined.
MEG data were low-pass filtered (7 Hz) before condition-specific event-related fields (ERFs) were calculated for correctly answered and artifact-free trials with a baseline of 200 ms prior to the onset of the critical word. Root mean square magnetic signals were aggregated over the channels of four regions of interest (left anterior, l. posterior, right ant., r. post.).
Source modeling was performed by calculating brain surface current density maps using realistic boundary element head models derived from high resolution T1-weighted anatomical MRI scans. The source compartment and the BSCD maps are displayed together with a transparent segmentation of each individual's cortical surface in order to allow to for a broad identification of the cortical regions of the identified sources.

3 Results

Neuromagnetic responses showed word category and context effects in an early time window (i.e., around 100 to 200 ms), and in a later time window. We focus here on effects in the time window of 400 to 600 millisconds, i.e., in the typical N400 time range.
The statistical analysis of the root mean square values yielded two main results. First, words presented in isolation elicited stronger activity than words presented together with a syntactic context ($p < .005$; cf. Fig. 1). Second, word category reliably interacted with the presence or absence of a syntactic context and with the factor region of interest ($p < .01$). By resolving this three-way interaction, a complex pattern became apparent. Nouns elicited greater signal strengths than verbs over the left posterior cortex when a syntactic context was present ($p < .05$; Fig. 1, left panel). In contrast, when presented in isolation, verbs showed slightly greater signal strength than nouns over the right hemisphere ($p < .1$; Fig. 1, right panel).

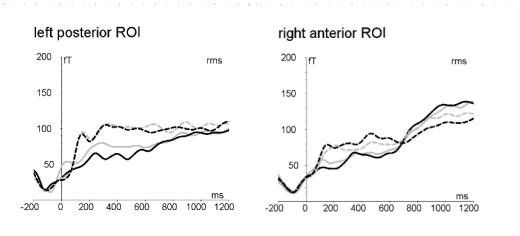

Fig. 1 Root mean square magnetic signals for two selected regions of interest. Black lines: verbs, grey lines: nouns. Solid lines: words presented in context, dashed lines: words without context. The left panel demonstrates that words without context elicited stronger responses than words presented in context. Furthermore, nouns in context elicited stronger magnetic responses than verbs in context in the left posterior ROI. In the right anterior ROI, it can be seen that verbs without context elicited slightly stronger activity than nouns.

The cortical localization of the reported effects can be described more precisely based on the analysis of individual brain surface current density maps. All four word conditions activated temporo-parietal and inferior frontal regions, stronger in the left than in the right hemisphere (displayed in a single representative subject in Figure 2). BSCD maps of difference waves support the results of the statistical analysis of the root mean square signal by showing that posterior temporal regions are more strongly activated by nouns than by verbs. In addition, BSCD difference maps also suggest stronger activity in left frontal areas for verbs than for nouns.

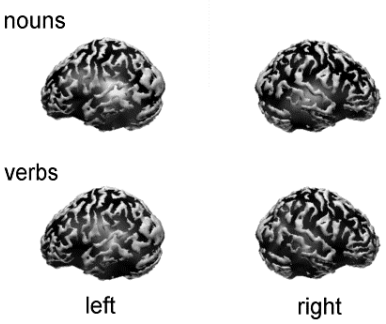

Fig. 2 Brain surface current density maps for verbs and nouns presented without syntactic context for one representative participant, displayed together with a segmentation of the cortical surface of this individual. The maps shown were calculated at 400 ms post stimulus onset.

4 Conclusion

The present results demonstrate the existence of segregated cortical representations for nouns and verbs. The finding of increased activity over posterior (i.e., temporal) areas for nouns and frontal areas for verbs within the left hemisphere is in support of models which suggest that objects and words representing objects (i.e., nouns) are represented in temporal cortex, whereas processing of actions and action words (that is, verbs) recruits brain regions involved in action execution [7,8].

However, this result is qualified by the finding that the described dissociation between nouns and verbs in the left hemisphere is contingent upon the presence of a syntactic context. When presented in isolation, the difference between verbs and nouns is manifested broadly over the right hemisphere. Isolated nouns and verbs elicited neuromagnetic responses of similar strength in the left hemisphere. Verbs perceived in isolation, however, elicited a stronger response over the right hemisphere or, alternatively, more broadly distributed magnetic fields, thus causing the (marginally significant) effect over the right hemisphere. This verb-specific activation increase might be attributable to the difference in the complexity of the lexical representation between verbs and nouns.

In conclusion, the present results indicate that differences in the pattern of cortical activity elicited in the left hemisphere only become detectable when the syntactic information associated with the words is required for correct processing.

5 Literature

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