Perception of Verbs and Nouns Monitored by MEG

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Introduction

It is widely accepted that the lexical entries of nouns and verbs differ with respect to a number of syntactic and semantic dimensions. However, it is not clear how these different word types are represented in the brain. From cognitive neuropsychology, it is known that focal brain damage can result in selective impairments of specific word categories [7]. For example, Daniele et al. [2] reported that patients with left anterior lesions were impaired in naming and comprehension of verbs, while a patient with lesions of the left temporal lobe showed a selective deficit in the processing of nouns.

Differences between the processing of visually presented nouns and verbs in lexical decision tasks have also been established using event-related potentials: In a syntactic priming paradigm, Samar & Berent [11] identified a positivity of verbs relative to nouns as early as 220 ms post-stimulus. It was taken to reflect the "initial availability of specifically lexical properties" (p. 266). Preissl et al. [10] also reported a positive component at about 200 ms for verbs compared to nouns. This activity was largest over frontal and central recording sites. These studies, however, do not allow inferences about the neural sources responsible for the ERPs to nouns and verbs.

It is of crucial interest to establish whether there is a correspondence between the neural generators identified in electrophysiological research of single-word processing and the specific patterns of breakdown from brain-damage described above. To investigate this issue, a multi-channel MEG study with auditory presentation of single words was conducted.

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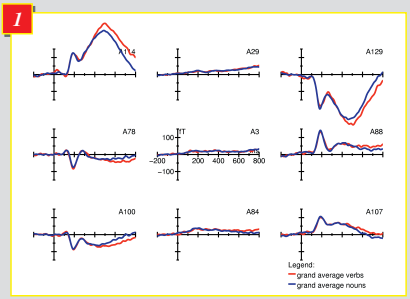

Time courses of six MEG channels calculated for the conditions noun and verb and measured over fronto-temporal, temporal and parieto-temporal regions.

Material and Methods

Stimuli

A pool of bisyllabic verbs and nouns that ended on an unstressed vowel 'schwa' was extracted from the CELEX-corpus (e-mail: celex@mpi.nl). In order to avoid an ambiguity in the infinitive form of German verbs, only verbs in the first person singular were selected. For the nouns, the nominative singular form was chosen. All words were controlled for the uniqueness of the word category. Furthermore, words with a frequency of occurrence of above 100 per million were excluded. In order to rank the level of concreteness, a pre-test was performed. For each of the nouns and verbs, two questions were answered by 75 persons:

1. To which word category does this word belong? (noun, verb, adjective, others)

2. How would you rank the concreteness of this word? (1=concrete,..,5=abstract)

Only words which were unambiguous in word category were included. To separate concrete from abstract words, two limits were defined: Concrete words were required to have a mean level of abstractness of less than 1.9. Abstract words were included if their abstractness was above 3.4. From the concrete verbs, only verbs associated with motion were selected. The concrete nouns included both animate and inanimate nouns. This resulted in the following four stimulus conditions:

- Concrete nouns
- Abstract nouns
- Concrete motion-verbs
- Abstract mental-verbs

The described procedure resulted in 40 stimuli per condition. For a target-detection task (see below), function words were chosen that were comparable to the stimuli with respect to word length and ending. Stimuli were spoken by a trained speaker to control for loudness and stress. Digitization was done via a DAT-tape recorder and a PC equipped with CSL technique (Key Instruments). Word onset and length were defined manually. The average word length was 500 ms.

Procedure

The experiment was run in three blocks, each containing the complete set of stimuli (i.e., 240) in a pseudo-randomized order. Across blocks, this procedure resulted in 120 stimulus presentations per condition. Words were presented with an ISI of 1200 to 1400 ms. The total length of one block was about 7 minutes. The participants' task was to press a button whenever a target word was detected. All measurements were made on weekends because of the reduced environmental noise level compared to normal working hours. For data recordings, a sampling rate of 254.31 Hz and a bandpass of 0.1 Hz to 50 Hz were chosen. A whole-head 148 channel neuro-magnetometer (Magnes, BTi) was used to collect the evoked response fields (ERF). 11 magnetic reference channels and 4 EOG channels were recorded to control for artefacts. BTi online noise suppression was activated.

Participants

Alltogether, 29 paid volunteers participated in the experiment. All of them were native speakers of German, right handed according to the Edinburgh handedness test and without known hearing deficits. To maximise the quality of the ERFs and to include only participants willing to remain in a fixed head position for about 10 minutes, participants were pre-selected on the basis of a simple-tone experiment. Nevertheless, due to low signal to noise ratios (SNR) in the main experiment, some participants had to be excluded from further analyses. The resulting 21 participants (11 female; mean age 23.2) provided SNRs of greater than 6.

Postprocessing

All datasets were low pass filtered with f_0 = 25 Hz. Two types of postprocessing were applied: First, an additional high pass filter with f_0 = 2 Hz was used to suppress low frequency noise and search for early ERF components. Secondly, the noise was modelled by a linear estimation method. Automatic artefact rejection was done by defining a threshold value for the standard deviation within a time window of 100 ms. Averages were calculated for each participant, each condition and each experimental block. The magnetometer channels of each average were transformed into a standard magnetometer position, allowing the averaging across blocks. Grand averages were calculated to allow for comparisons of the four conditions, as well as the two collapsed conditions (i.e. verbs and nouns). Nine regions of interest (ROI) and two time windows around the maximum deflections were defined for the statistical analysis.

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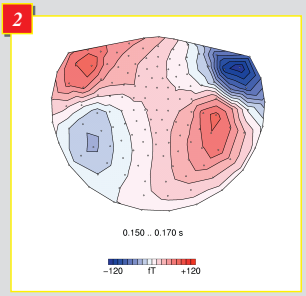

Magnetic field distribution of the verb condition at peak maximum.

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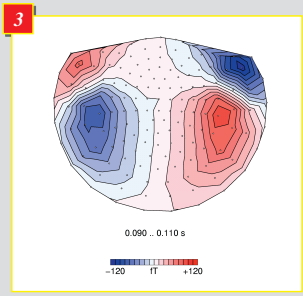

Magnetic field distribution of a typical N100m response in an experiment with simple sinusoidal tones at peak maximum.

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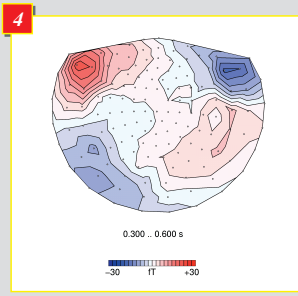

Magnetic field distribution of the difference between verbs and nouns averaged over the interval 300..600 ms.

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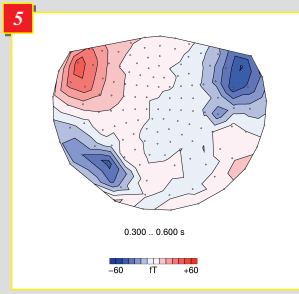

Magnetic field distribution of the difference between semantically incorrect sentences and correct ones. 0 ms is the beginning of the critical word.

Results

Participants performed the target detection task at 98% correctness and with a mean reaction time of 808 ms (160 ms std. dev.). After the experiment, most of them (75%) reported, that they solved the task by classifying the category of each stimulus. The others reported, that they memorized the complete list of target words.

After low pass filtering, the ERFs was superimposed by slow, nearly linear drifts that can be attributed to a source outside the experimental setting. These drifts were removed completely from the data by bandpass filtering which, on the other hand, reduced ERF amplitudes and created additional peaks around the existing ones (i.e. artefacts of on-line highpass filtering). No significant differences were found between experimental conditions or between the two collapsed conditions of nouns and verbs. The grand average of each condition showed an ERF around 170 ms followed by a long lasting activity that peaked around 500 ms (Fig. 1). These components were visible in both the lowpass filtered and the bandpass filtered averages. Two field extrema of about the same intensity (right 120 fT, left 100 fT) were visible over each hemisphere in a distance of about 7 centimeters, suggesting cortical sources in each hemisphere (Fig. 2).

The distribution of the ERF around 160 ms was comparable to that of components associated with activity of the region of the primary auditory cortex, e.g. a typical N100m from a simple tone experiment (Fig. 3). Topographically, the distribution of the second component differed from the first one: The most pronounced effects were found above left and right fronto-temporal regions. The second effect displayed a pronounced extremum over each hemisphere and a weak one (Fig. 4). A comparable field distribution was found in an earlier experiment [8] at about 500 ms (Fig. 5)

Discussion

The auditory stimulation caused activation of the primary auditory cortex. Words produced N100m-like field patterns 60 ms later than simple tones. Even stronger fields were elicited for words by the later component around 500 ms. Each of the presented words caused a field peaking above fronto-temporal regions (250 fT), which is in good agreement with earlier auditory perception studies of sentences [8] or words [9].

The auditory comprehension of different word categories like verbs and nouns was expected to differ at an earlier (about 200 ms) and a later (about 500 ms) stage.

Word category information is critical at the earlier stage as it is the basis for initial phrase structure building. Hahne and Friederici [5, 6] demonstrated in an experiment on auditory sentence comprehension, that an ERP deflection around 150 to 200 ms and elicited by a word category violation, is not influenced by some experimental variations modifying the attention. This supports the assumption of a rather automatic functional unit.

The later stage is assumed to reflect lexical-semantic processes involving information of meaning and information about the theta roles a verb can take. Given that verbs are generally more complex than nouns due to the theta role information they carry, they should cause a higher or delayed activity. This can be supported by findings of Gomes et al. [4], who observed significantly later N400 for verbs than for nouns in the visual and auditory modality.

The absence of a significant difference between the experimental conditions may be discussed on the basis of the following hypotheses.

The first hypothesis is, that the single word presentation did not activate the word category classifier in the same manner as during sentence processing, although the target detection task for the participants was chosen to force them to process the word category. Most of the participants reported that they used this strategy. But, according to linguistic theory [1], the classification of verbs and nouns might be done on a lexical level by activating structural features as [+N-V] for nouns and [-N+V] for verbs, respectively. The activation of this binary feature distribution does not seem to be costly, thus causing no difference within the evoked fields/potentials.

Instead of weak activity, a second hypothesis is, that the hearer uses a phonological difference between noun and verb inflections to support early classification. This, however, was not possible for the present stimuli as they were chosen to end in a category-ambiguous inflection. ERP studies reporting an early word category effect always used unambiguous inflections. A very recent ERP study of Hahne and Friederici (personal communication) even shows that this effect can be elicited by pseudowords in a sentence comprehension paradigm, whenever these were inflected unambiguously.

The third hypothesis is, that the effect of the verb-noun difference in ERP data, that was reported for visual stimulation, could stem from regions silent for the MEG method. It was impossible to conclude from the above mentioned references, whether the authors attributed their effects to e.g. deep sources or gyral sources.

Future research will address the last argument by simultanous EEG and MEG data recordings. A minimal syntactic context should introduce a higher need for on-line word category classification.

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