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An fMRI study on conceptual, grammatical, and morpho-phonological processing

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Abstract

The aim of the present study was to determine whether processing of syntactic word information (lemma) is subserved by the same neural substrate as processing of conceptual or word form information (lexeme). We measured BOLD responses in 14 native speakers of German in three different decision tasks, each focussing specifically on one level of lexical processing (conceptual, syntactic, and morpho-phonological). The test parameters were natural gender, grammatical gender, and word form derivation, respectively. Discrimination between words played backwards and complex sounds served as control task. Complex contrasts revealed a functional fractionation of the left inferior frontal gyrus for each level of lexical processing.

Keywords: Mental lexicon; Lemma; Lexeme; Natural gender; Grammatical gender; Left inferior frontal gyrus; FMRI

1. Introduction

The mental lexicon is considered to constitute the interface between conceptualization and grammatical and phonological encoding/decoding of an utterance. Each lexical entry comprises semantic and syntactic information (lemma) as well as information on the morpho-phonological form (word form; lexeme). It is still a matter of debate whether the syntactic properties of a word and its morpho-phonological form are represented on two different levels and whether the retrieval of word forms is necessarily mediated by the lemma level (Miozzo & Caramazza, 1997). Evidence in favour of a lemma representation distinct from the word form representation comes from a large number of studies both in normal speakers (speech errors and tip-of-the-tongue phenomena) and in aphasic patients (lexical retrieval disorders) (for a review see: Levelt, Roelofs, & Meyer, 1999).

In the past decade, numerous brain imaging studies have been carried out to uncover the neural correlates of single word processing. For conceptual and semantic processing, activations were observed in left inferior frontal areas, in posterior parietal areas and/or in temporal areas (e.g., Zahn et al., 2000). All studies showed involvement of the left inferior frontal areas as a necessary part of the so-called semantic network of the left hemisphere (for a review see: Bookheimer, 2002). So far no evidence is available to what extent this network is based on semantic and/or conceptual information in the strict linguistic sense.

Studies on word form (lexeme) processing reported activations in Broca's area and in the supramarginal gyrus (e.g., Moore & Price, 1999) whereas studies focussing on processing of lemma information identified Broca's area (e.g. Heim, Opitz, & Friederici, 2003).

In a recent event related fMRI study using homonyms, Weis, Grande, Pollrich, Willmes, and Huber (2001) could distinguish two different patterns of activation for conceptual processing (left inferior frontal gyrus) and word form processing (left inferior parietal

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cortex). The aim of the present study was to determine whether processing of syntactic information (lemma) is subserved by the same neural substrate as processing of conceptual and word form information (lexeme). For this purpose, we measured BOLD response during decision tasks in native speakers of German.

2. Method

2.1. Tasks and procedure

Three different decision tasks were designed, each one focussing specifically on one level of word processing. For the conceptual level, the parameter chosen was natural gender (''concept condition''). Since decision on natural gender can in most cases be based on grammatical gender, subjects were required to make an indirect judgement on natural gender by answering whether the denoted objects have a penis or not. This was necessary to avoid that the subjects might apply an ''article strategy'' for decision. For the lemma level, the parameter was the grammatical gender. Here, subjects had to decide whether the appropriate article for the heard words is ''DER'' (the—masc.) or not (''lemma condition''). Finally, for the lexeme level, we had a derivation task in which subjects had to determine whether adding the ending ''-IN'' (suffix for derivation of the feminine form) to the presented nouns results in actual German words or not (''lexeme condition''), cf. LEHRER-IN (teacher), *ONKEL-IN (uncle).

The stimuli for the concept condition and the lexeme condition consisted of nouns of animals (e.g., KATER—male cat; STUTE—mare) or of persons (e.g., SPORTLER—sportsman; ONKEL—uncle). The stimuli for the lemma condition consisted of non-living objects (TEMPEL—temple; BIBEL—bible); we included only nouns with a morphological or phonological form which does not allow prediction of the correct grammatical gender.[1] The frequency of occurrence and the number of syllables of the items were controlled and balanced across conditions. Frequency estimates were taken from the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993). The mean total frequency of occurrence was 19 per million (range 0–136) for the concept condition, 22 (range 0–84) for the lemma condition, and 22 (range 0–137) for the lexeme condition. The stimuli were mono- and disyllabic with a mean of 1.7 syllables for the concept condition, 1.55 for the lemma condition, and 1.7 for the lexeme condition. Each item occurred only once in the experiment.

[1] Presently, we are replicating the experiment with lemma stimuli that consist of animate nouns like the two other conditions. Preliminary analysis of the data ($n = 8$ subjects) showed the same results as reported here.

The stimuli were presented through headphones. The answer criteria for each task as well as the answer possibilities (YES/NO) were presented visually through goggles. Subjects responded by pressing a two key button with their left hand (middle finger YES, index finger NO).

To control for sensory and motor activations (auditory and visual input; key pressing) a control condition was included. This consisted of a discrimination task between language-like items (words played backwards) and non-language-like items (complex sounds).

The fMRI-experiment was carried out in a single session. Every condition was repeated four times in blocks of 30 s with 10 items each (1 stimulus every 3 s). The order of conditions was: control (1)–lemma (4)–control (1)–lexeme (4)–control (1)–concept (4)–control (1). Immediately before each experimental block there was a 17 s rest followed by the instruction for the next task (3 s). After the fMRI-experiment, the subjects were interviewed on the strategies used for solving the tasks.

Whole brain fMRI was performed on a 1.5 T Philips Gyroscan NT with a standard head coil and echo-planar imaging (TR 2.9 s, TE 50 ms, FA 90°, Matrix 64×64, FOV 220 mm, 30 contiguous 4 mm slices parallel to the AC-PC line). The data were analyzed with SPM2 (Wellcome Department of Imaging Neuroscience, London UK). Functional images were spatially realigned, normalized into a stereotactic space, and smoothed with a Gaussian filter ($12 \times 12 \times 12$ mm). A random-effect analysis was performed. Only clusters comprising at least 5 voxels and having uncorrected p values for individual voxels of at least .01 were considered.

2.2. Participants

A total of 14 young, male, right-handed, monolingual native speakers of German participated in the study and gave informed written consent. Their mean age was 24 years (range: 21–32 years).

3. Results

All experimental tasks were solved with high accuracy (percentage of correct responses: 95% for the concept condition, 93.75% for the lemma condition, and 94.46% for the lexeme condition). As regards the strategies applied to solve the tasks in the three conditions, the interviews revealed that the participants used strategies rather consistently. For the concept task, visual imagery and/or verbal description were reported. In the lemma condition, the subjects actively searched for the appropriate article, only three participants relied on intuitive grammatical judgements. The lexeme task was mainly solved by lexical judgements after adding the suffix to the presented word. Only three subjects decided for