Stem-, Spraak- en Taalpathologie
Vol. 13, 2005, No. 1, pp. 49-55

32.8310/05/1301-49

Different levels of lexical processing – evidence from an fMRI study with normal subjects and aphasic patients

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Psycholinguistic models assume different levels of lexical processing: the conceptual, the lemma- and the lexeme level. The aim of the present study was to disentangle the neural substrates of these different levels in normal subjects and to investigate mechanisms of functional reorganisation of lexical processing in two aphasic patients.
14 young, right-handed, native speakers of German participated in the fMRI-study consisting of three different decision tasks each focussing particularly on one level of lexical processing. Additionally we examined two aphasic patients (RK and WR) with left hemisphere lesions.

In the normal subjects we found activation for the concept condition in the anterior part of Broca's area (BA 45) and the frontal operculum (BA 47), for the lemma condition activation was observed in the posterior part of Broca's area (BA 44) and the lexeme condition revealed an increase in BOLD response in both the anterior and the posterior part of Broca' area (BA 45 and 44).
Behavioural data show that the lemma task was by far the most difficult for both patients. They showed no left inferior frontal activation during this task. Instead activation was observed in left perilesional (RK) and right frontal and parietal areas (WR) respectively.

Introduction

Levelt (1993) assumes different levels of lexical processing. During word reception, the phonological word form is decoded retrieving information from the lexeme level, whereas processing of grammatical information like word category, verbal argument structure or grammatical gender requires access to the lemma level. The meaning

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of a word is understood on the conceptual level. While the conceptual as well as the lexeme level are widely accepted, there is an ongoing debate whether or not the lemma level is necessary to mediate between conceptual and word form processing (for a review cf. Levelt, Roelofs & Meyer, 1999).

Numerous neuroimaging studies have been carried out to disentangle the neural substrates of lexical processing in healthy subjects. Studies on semantic and/or conceptual word processing have shown the so-called semantic network, which includes left inferior frontal, posterior parietal and temporal areas (for a review cf. Bookheimer 2002). Activations in Broca's area and the left supramarginal gyrus have been reported for processing of phonological word forms (lexemes) (e.g. Moore & Price 1999). As regards processing of grammatical (lemma) information, activation was observed in Broca's area (Heim, Opitz & Friederici, 2003).

The present study does not focus only on lexical processing in healthy subjects but also in aphasic patients. The aims were on the one hand to differentiate between the neuroanatomical correlates for the three levels of lexical processing in healthy speakers and on the other hand to investigate the functional reorganisation after left hemisphere brain damage. Different mechanisms are assumed to explain recovery of lexical processing in aphasic patients. While some authors emphasize the role of the right hemisphere (e.g. Weiller et al. 1995), others postulate that good recovery relies on perilesional left hemisphere activation (e.g. Heiss et al. 1999).

Method

Experimental conditions and materials

To differentiate between the specific brain areas involved in processing at each assumed lexical level three different choice reaction tasks were designed. The stimuli were presented auditorily, while the instruction for each task was presented visually. The subjects were asked to answer by pressing a two key button with their left middle ("yes") or index finger ("no"). In the concept condition, the subjects had to decide whether the natural gender of the denoted animal or human being was male (e.g.: *Kater (tomcat)* "yes"; *Stute (mare)* "no"). In the lemma condition, the question concerned grammatical gender, i.e. whether the masculine article *der* was the correct one (e.g. *Tempel* "yes"; *Gabel* "no"). The lexeme condition required adding the suffix *–in* to the presented word (animal or human being) and deciding whether this resulted in an existing German word or not (e.g. *Lehrer (Lehrerin)* "yes", *Onkel (*Onkelin)* "no"). An additional task was used to control for auditory and visual input and motor response. The subjects had to differentiate between language-like (words played backwards) and non-language-like-stimuli (complex sounds).

In all conditions mono- and disyllabic German nouns were used as stimuli. The grammatical gender of nouns presented in the lemma condition was not predictable according to phonological or morphological cues. The stimuli of all three lexical

conditions were controlled for number of syllables and frequency of occurrence as assessed with the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993). Each stimulus occurred only once in the experiment.

Image acquisition and analysis

The fMRI study was carried out on a 1.5T Philips Gyroscan NT in one session (TR 2.9s, TE 50ms, FA 90°, Matrix 64 x 64, FOV 220 mm, 30 contiguous 4 mm slices parallel to the AC-PC line). Image analysis was performed with SPM2 (Wellcome Department of Imaging Neuroscience, London UK). For the control group, data were analysed in a random effects analysis. Only clusters comprising at least 5 voxels and having uncorrected p-values for individual voxels of at least .01 were considered. Peaks of activations are given in coordinates referring to the Talairach and Tournoux stereotactic space (Talairach & Tournoux, 1988). The data of the two patients were analysed separately as single cases. Due to the lesion the patient's images were not normalized. The patient's results were therefore projected onto each individual brain.

Participants

14 male, right-handed students (mean age 24 years; range: 21-32 years), all native speakers of German, took part in the fMRI experiment. Two aphasic patients were included in the study, one patient with a left anterior and one patient with a left posterior perisylvian lesion. Both patients were male right-handers.

Patient RK, a 47-year-old software engineer, had suffered from a left posterior MCA-infarction 19 months before the fMRI examination. At the time of scanning, he presented with a mild hemiparesis and a mild to moderate non-classifiable aphasia with mostly syntactic difficulties and very good speech comprehension. His lesion comprises the posterior part of the superior temporal gyrus (Wernicke's area) and the adjacent part of the inferior parietal cortex.

The second patient, WR, a 61-year-old physicist, had suffered from a left anterior MCA-infarction. His lesion includes almost all of Broca's area. 9 months post onset he had only residual aphasic symptoms, concerning above all written language, including a phonological dyslexia and dysgraphia.

Results

Group study

The behavioural data show that accuracy during scanning was high in all tasks (concept task 95 %, lemma, lexeme and control task 94 %). The lexeme task was reported

to be the most difficult one, because two steps were included: the suffixation and the lexical decision. In all three lexical tasks as well as in the control task activations were observed in the left perisylvian and the cingulate cortex. After subtraction of the control task, the subjects showed activations in the left inferior frontal gyrus for all three lexical conditions. The foci and the extension of activations in the left inferior frontal gyrus were different for each level of processing. In the concept task, the anterior part of Broca's area (BA 45, activation peak -44, 20, 21) as well as BA 47 (peak -51, 39, -2) were activated. For the lemma task, activation was found in the posterior part of Broca's area (BA 44, peak -44, 12, 14). The lexeme task yielded activation in both parts of Broca's area (BA 44 and 45, peaks at -44, 12, 14 and -55, 28, 10).

Patient RK

RK's accuracy during the fMRI examination was relatively high except for the lemma task (concept task 70 %, lemma task 40 %, lexeme task 73 %, control task 85 %). Patient RK (posterior lesion) showed activation in the left inferior frontal gyrus during the concept condition in an area quite similar to the normal subjects. In the lemma condition no inferior frontal activation was found even though this area is structurally intact. The lemma task instead led to activation of the right insula and of the perilesional posterior part of Wernicke's area and the inferior parietal lobule. As regards the lexeme task, activation of the left inferior frontal gyrus was found as well as activation of the right insula and perilesional posterior temporal and inferior parietal areas. The missing activation in the inferior frontal gyrus during the lemma task corresponds to the exceptionally low performance in this task.

Patient WR

Even though WR's accuracy in the scanner was higher than RK's, he also had most problems with the lemma task (concept task 90 %, lemma task 55 %, lexeme task 75 %, control task 95 %). In the concept condition, WR showed activation of the left thalamus, the left superior frontal cortex and the right insula, but no activation of language specific areas in the left hemisphere. In the lemma condition, the only left hemisphere activation was again found in the thalamus. Additionally, the right insula and the right inferior parietal cortex were activated. For the lexeme task, left hemisphere activations were found in spared parts of Broca's area, dorsal to the lesion, and in the thalamus in addition to the right insula and the right inferior parietal cortex.

Discussion

Lexical processing in normal subjects

Using three different choice reaction tasks, it was possible to disentangle those areas, which specifically subserve lexical processing at each specific level. The normal subjects showed three different patterns of activation in reference to these three levels. While access to conceptual knowledge led to activation in the anterior part of the left inferior frontal gyrus (BA 45 and 47), which is known to be part of the semantic network, access to grammatical knowledge, i.e. lemma information, revealed activation in the posterior part of the inferior frontal gyrus (BA 44), an area often reported in connection with syntactic processing (e.g. Stromsworld et al. 1996). Friederici, Opitz & von Cramon (2000) reported a similar fractionation of the left inferior frontal gyrus using decision tasks on semantic properties (concreteness) in contrast to grammatical features (word category).

In the lexeme task, an extended activation was observed, comprising both the anterior and posterior part of the inferior frontal gyrus. This may be due to the fact that this task includes both morpho-phonological and semantic aspects. The cluster of activation in the lexeme task, however, is larger than those of lemma and concept task taken together. Therefore, we assume that the lexeme task requires more than only lemma processing plus conceptual processing. In sum, these three lexical conditions show that the inferior frontal gyrus is specifically fractionated for level of lexical processing.

Lexical processing in aphasic patients

The two patients – one with a left posterior, the other with a left anterior perisylvian lesion – have shown different patterns of recovery. Both patients had most difficulties with the grammatical gender decision, whereas the natural gender decision was much faster and more accurate. This dissociation between grammatical and conceptual processing has often been reported.

In the lemma task, RK, the patient with the posterior lesion, showed the lowest performance and no left inferior frontal activation, instead activation was found in left posterior – perilesional – areas and the right insula. For WR, who was better than RK but also not nearly as good as the control group in the lemma task, again there was no activation observed in the left inferior frontal gyrus. Instead activations were found in the left thalamus and in right frontal and parietal areas. Both patients showed mainly contralateral activation together with poor performance in the lemma condition. This underlines the importance of the left inferior frontal gyrus for lexical, especially grammatical processing. On the other hand patient RK shows activation of left inferior frontal areas during the concept task, where his performance is far better. This supports the view of Heiss et al. (1999) and Karbe et al. (1998), who postulate that

good outcome relies on the reactivation of left hemisphere perilesional areas.

To explain why RK shows no activation of his structurally intact left inferior cortex in the lemma task while he activates the same region in the two other tasks, a mechanism described by Price et al. (2001) as *dynamic diaschisis* has to be taken into consideration. This mechanism explains the context-sensitive effect a lesion may have on the evoked response of a distant cortical area.

In all three tasks, WR shows activation of the left thalamus, nonetheless no activation of left hemisphere language areas in the concept and the lemma condition. This is surprising taking into account his high performance in the concept task. Only the lexeme task yields activation of the remaining tissue of Broca's area. Additional activation is found in the right insula and the right inferior parietal cortex, both areas belonging to the language network, but usually activated in the left hemisphere or bilaterally.

To clarify whether the activations observed in WR and RK were also found in normal subjects, a single case analysis was carried out for the control group. Even though all of the activation foci described for RK and WR were found in some of the controls, their activation pattern remains different. Especially activation of the insula was found in some control subjects, in most of them, however, bilaterally and not only in the right hemisphere. It is interesting to note that there were also normal subjects who did not activate the left inferior frontal cortex in the lemma task. Nevertheless these subjects showed the same high accuracy in this task as the ones with left inferior frontal activation.

The question remains, whether the different activation pattern of the two patients is really due to their lesions or whether the relevant factor is the different age. The control group consists of young persons with a mean age of 24 years while the patients are 47 resp. 61 years old. Grossman et al. (2002) found age-related differences in brain activation in a sentence comprehension task. The authors argue that these changes are the result of an upregulation of working memory in order to support sentence processing. Caplan et al. (2003) demonstrated that not age, but proficiency (measured by speed of processing and probably related to years of education) is the relevant factor. The elder participants in the study of Grossman et al. (2002), however, were as highly educated as the younger ones, which means that the differences cannot be explained by years of education. Thus the influence of age on the activation pattern remains controversial.

Conclusion

We have shown two single case fMRI studies on lexical processing in aphasia in comparison with a group of 14 normal subjects. The results of the normal subjects underline the fact that the left inferior frontal cortex is specifically fractionated for level of lexical processing. Overall, the two patients showed high variability in functional reorganisation of lexical processing. This stresses once again the importance of single case reports to study recovery of brain function in aphasia.

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