Perception of syntagmatic segmentation: a PET study.

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ABSTRACT

The present PET study investigates the role of prosodic clues (pitch, pause) in processing the oral speech syntactic structure. The stimuli used were syntactically simple sentences and sentences with different syntagmatic segmentation. They were presented binaurally to twelve right-handed, musically untrained native Russian speakers. One condition reflected automatic perceptual processing, the other understanding of meaning. Significantly increased brain responses occurred in the right inferior posterior frontal region (BA 44, 45,9) and in the right cerebellum (medio-inferior area) in the second condition. The results further support the notion that auditory speech comprehension is not restricted to the left hemisphere. The underlying mechanisms and the respective role of the right hemisphere and cerebellum structures during speech processing are discussed.

1. INTRODUCTION

These mechanisms of auditory speech perception deal with the segmenting pause and tonal changes, thus, the question arises of how the data on syntax processing correspond with the necessity to process prosodic clues for syntax comprehension in oral speech. Syntax processing in sentence reading studies was described to occur primarily in left hemispheric regions emphasizing the importance of the left inferior frontal gyrus [1, 2, 3, 4, 5] with the right homotopic cortices being activated to a weaker extent, while an important role in the prosodic features processing belongs to the right inferior frontal cortex, reported to be involved in pitch and tone perception [6, 7].

In our PET study we used audially presented sentences with syntagmatic segmentation, where the place of a semantic pause changes the syntactic structure and the meaning of a sentence.

2. METHOD

Twelve right-handed, musically untrained subjects, native Russian speakers. Four stimulus conditions were presented twice to each subject for a total of 8 tasks in a single session. The conditions used were the following:

Condition 1*:* Phrases with syntagmatic segmentation were presented. binaurally The distracting task was to press one key in case a presented phrase had a word beginning with /d /, and another key – if not. For example, the phrase - was: “ To take not, to leave”. On the screen it was written: “word, beginning with /d /, yes / no”.

Condition 1C*: control to Condition 1):* Phrases without syntagmatic segmentation were presented binaurally. The task - as in Condition 1. For example, the phrase - was: “ It was warm in a room”. On the screen it was written: “word, beginning with /d /, yes / no”. ***Condition 2****:* Phrases with syntagmatic segmentation were presented binaurally. Subjects were to choose the correct meaning of a phrase from the two, given on the screen and to press the relevant key. For example, the phrase - was: “ To run, not to stand ”. On the screen it was written: “It is necessary: to stand / run”. Or the phrasewas: “ Peter, - said Ivan ”. On the screen it was written: “Who said? Ivan / Peter”.

Condition 2C *(control to Condition 2):* Phrases without syntagmatic segmentation were presented binaurally. Subjects were to choose the correct meaning of a phrase from the two, given on the screen and to press thethe relevant key. For example, the phrase was: “ Father bought him a coat ”. On the screen it was written: “Father bought him: a coat / a watch”.

For the blood flow level data gathering a PET camera PC2048-15B was used, which permits to obtain 15 axial slices of brain with the spatial resolution of 5-6 mm. The temporal resolution, originating from the time of data

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gathering in our study, is 60 sec. The radiopharmaceutical used was 1.5 ml of water with radioactive oxygen - 15 (a half-life period 123 sec.) in a dosage of 0.86 mCu/kg.

After reconstruction of PET-images, they were processed by Statistical Parametric Mapping method (SPM99) which is one of the standard methods for processing the physiological PET-data [8] and allows to allocate areas of activation, that is an increase in the local cerebral blood flow (CBF) in one condition relative to another, taken as control (a cognitive subtraction method).

Comparisons of conditions in our study (“ the test condition minus the control condition”) were supposed to distinguish the following cognitive processes:

Change of activity in the system of the automatic analysis of prosodic characteristics of the speech stimuli (subtraction condition ”1 – 1C ”);

Change of activity in the system of the active (realized) analysis of prosodic characteristics of the speech stimuli (subtraction condition ”2 – 2C ”)

Behavioral measures (response time, response accuracy) were also collected during the scanning period.

3. RESULTS AND DISCUSSION

Significant CBF increase was observed in subtraction conditions ”2 – 2C ” and ”2C – 2”.

In ”2 – 2C ” subtraction condition (Figure 1) areas of the blood flow increase were in the right inferior posterior frontal region (BA 44, 45,9) and in the right cerebellum (medio-inferior area).

In ”2C – 2” subtraction condition (Figure 2) we observed activations in the perisylvian area of both hemispheres: BA 41, 42, 13 in the right hemisphere and BA 41, 42, 22, 13 in the left hemisphere.

In ”1– 1C” and ”1C – 1” subtraction conditions there were no significant CBF increases.

The absence of reliable activations in comparisons of automatic processing of syntagmatic segmentation (i.e. in comparisons "1-1C" и "1C-1"), apparently, is explained by very small distinctions in activation between these conditions, laying outside the used statistical criterion. However, the deliberate performance of the similar task (in a condition "2") causes significant amplification of corresponding activations (comparison "2-2C").

Activation of right inferior frontal area and right hemisphere of a cerebellum during deliberate processing of syntagmatic segmentation, most probably, reflects the brain parsing of semantic and phonetic characteristics, isolating a syntagma.

From the phonetic point of view, syntagma is the chain of words connected by the uniform intonational structure. Parcing of speech flow to syntagmas is achieved by two mechanisms. One is a dividing role of a pause between syntagmas, the other is pitch difference between the end of the syntagma, previous to a pause, and the beginning of a syntagma, subsequent to a pause.

Probably, an important role in the intonational factor processing belongs to the right inferior frontal cortex, reported to be involved in pitch and tone perception [6, 7]. This explains participation of the right prefrontal area in the perception of linguistic (in our research), and emotional (in the other data, e.g., [9]) prosody.

The other activation, registered in "2-2C" comparison in the right hemisphere of cerebellum, can be connected with parsing the other important parameter of syntagmatic segmentation - pauses between syntagmas. Cerebellum is frequently considered as the key structure, participating in the estimation of time intervals that is necessary for many kinds of sensomotor and cognitive activity [10, 11]. Besides, the cerebellum right hemisphere, according to the present data, is morphologically (through thalamic nuclei) and functionally connected to contralateral frontal cortex, including Broca’s area [12, 13].

It is possible also, that the role of the right cerebellum activation is associated with estimation of phonetic and semantic links existing inside syntagmas and disrupting at their borders, or with keeping the structure of a phrase in a working memory while processing (for the review see [13]). Phrases with syntagmatic segmentation, used in test condition 2, presumably, activate the corresponding brain systems more, than phrases without the syntagmatic segmentation, used in the control 2C.

Syntagmatic segmentation in orally presented phrases allows to understand their syntactic structure. In visual presentation punctuation serves the same purpose. . It is possible to assume, that brain mechanisms of syntactic processing should be the same for various modalities of presentation. However, the studies of visually presented syntactic structures mainly show the role of left hemisphere areas [e.g., 1, 2, 3, 4, 5]. In the present study we've seen no activations in the left hemisphere in "2-2C". comparison Probably, it is caused by the fact that the stimuli in a control condition were presented not in separate words, as in the majority of studies, but by the words, organized in phrases, though thie set was syntactically more simple, than in a test condition.

The increase of blood flow in the left perisylvian cortex in a control condition "2C", compared with the test condition "2", can be explained by the fact, that the reaction time to the stimuli in condition "2C" was smaller, than in condition "2", and, thus, more phrases were included into a scan in condition "2C", that increased the acoustical load in this condition.

4. CONCLUSIONS

The right inferior posterior frontal region (BA 44, 45, 9) and in the right cerebellum (medio-inferior area) contribute to oral speech syntactic parsing, being involved in pitch and pause processing. There is a difference in brain mechanisms, underlying oral and visual syntactic structures perception.

Thus, we believe that in our study the right posterior inferior frontal gyrus activation reflected the perception of pitch boundaries of the semantic pause. We also presume that the right cerebellum activation in our study is due to the semantic disruption in sentences, caused by the pause. The left perisylvanian cortex, earlier reported to be involved in visual syntactic processing, in our study was considerably more activated in control conditions rather than in the test ones. Dependence of brain activation on different presentation modalities supports the idea of syntactic processing being not strictly localised in the brain.

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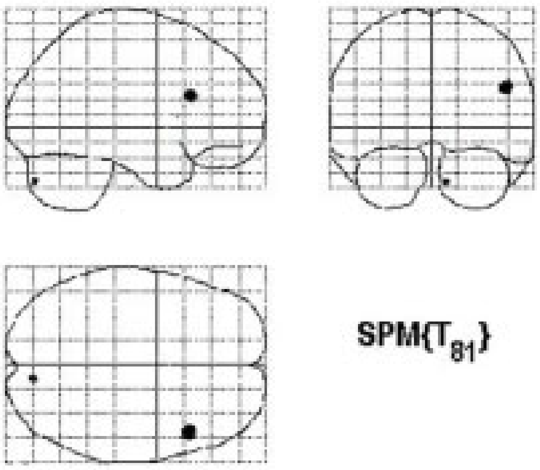

Figure 1: CBF increase in subtraction condition "2 – 2C "

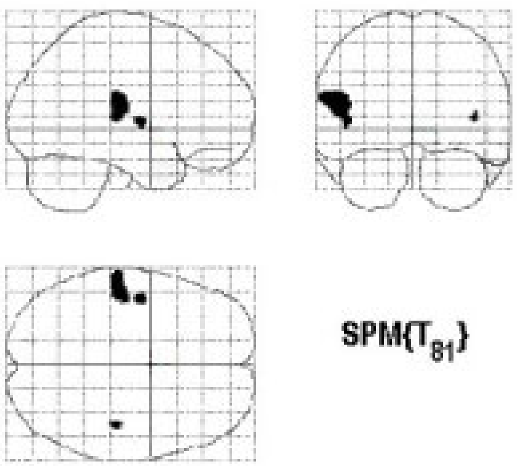

Figure 2: CBF increase in subtraction condition "2C – 2 "

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