

A PET Study of the Brain Mechanisms Underlying Perception of Phrases with Syntagmatic Splitting

K. S. Strel'nikov*, V. A. Vorob'ev*, M. S. Rudas*, T. V. Chernigovskaya**, and S. V. Medvedev*

* *Institute of the Human Brain, Russian Academy of Sciences, ul. Akademika Pavlova 9, St. Petersburg, 197022 Russia*

** *St. Petersburg State University, Universitetskaya nab. 7/9, St. Petersburg, 199164 Russia*

Received April 8, 2003

Abstract—Positron emission tomography (PET) was used to localize the brain regions involved in the processing of pauses and intonation changes, which underlie the syntactically correct perception of auditory verbal stimuli. Subjects were asked to listen to a phrase and to choose a correct answer from two variants presented on a monitor screen. Differences in cerebral blood circulation were mapped for perception of phrases containing or lacking a pause determining the meaning. Conscious analysis of the phrase structure was associated with activation of the right lower prefrontal area and the right posterior medial area of the cerebellum. The possible role of these brain structures in analyzing factors of syntagmatic splitting is discussed.

Syntagmatic splitting is a phonetic mechanism realized at the phrase level. It is therefore a prosodic characteristic of speech [1].

Until recently, this problem was generally regarded in view of hypotheses of the hemispheric specialization of brain functions, on the basis of observations of patients with unilateral brain damage, experiments with intracarotid injections of amobarbital, and tests with dichotomous listening [2]. According to one hypothesis, specialization of brain hemispheres is expressed only at the level of acoustic signal characteristics, so that the rhythmic structure of speech is processed in the left hemisphere whereas the tone characteristics are analyzed in the right hemisphere [3–5]. According to another hypothesis, the involvement of a particular hemisphere depends on the linguistic communicative function of a particular prosodic phenomenon. For example, the right hemisphere is mostly involved in the analysis of emotional prosody [6–11], and the left hemisphere, in the analysis of linguistic prosody [12]. Some works, however, have questioned the possibility of distinct hemispheric specialization of prosodic functions [13]. Relevant studies have revealed not only different roles of the hemispheres, but also their interaction and its dependence on the kind of linguistic prosody [14, 15].

In addition, clinical neuropsychological studies have revealed that, although the right hemisphere plays a key role in analyzing affective prosody, the analysis may be dramatically impaired by disturbances of inter-hemispheric relationships as a result of damage of the white matter in proximity to the medial rostral areas of the corpus callosum [16].

A bioelectric response coinciding with the intonation borders within cues has been observed using the evoked potential method [17]. In addition, magnetic

responses (*N400m*) to disturbances of lexical and prosodic (intonational and phonemic) characteristics of words in a phrase have been recorded using magnetic encephalography (MEG) [18]. However, the methods of evoked potentials and MEG have been very rarely used to study prosody processing in the brain.

Noninvasive methods of volume scanning of the brain, such as positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) have come into broad use in the last two decades. This has made it possible to precisely localize the brain areas involved in prosodic analysis both in patients and in healthy subjects. Studies employing these imaging methods have supported the involvement of the right hemisphere, in particular, the right lower frontal cortex, in the perception of emotional prosody. The left lower frontal area proved to be activated mainly in tasks involving phonetic analysis [11]. Furthermore, it has been found that the left lower frontal area (Broca's area) is activated in tasks requiring analysis of tones only in speakers of so-called tonal languages (Thai and Chinese), with differences in tone affecting the word meaning. No such activation of Broca's area was observed in speakers of English, a nontonal language [19].

Analysis of the brain mechanisms of perception of individual variants of prosody is a natural continuation of research in this field. However, most researchers have considered only emotional prosody thus far, and only a few works have focused on another important aspect of prosody, linguistic prosody, which is closely associated with the syntactic structure of phrases.

In this study, we focused on syntagmatic splitting, which is one of the most important components of linguistic prosody and functions as a key for perception of syntactic margins in a phrase, i.e., is a phonetic mecha-

nism that reveals the structure of sentences in speech. The main aim of this study was to localize the brain areas involved in this process by means of positron emission tomography.

METHOD

We used PET to record the changes in the local cerebral circulation rate proportional to the local level of excitatory or inhibitory activity [20].

The study involved 12 male volunteers aged from 18 to 35 years; the subjects had normal vision, were right-handed (according to the Edinburgh Inventory [21]), had at least a secondary education, and were native Russian speakers. They were healthy according to the results of a medical examination and laboratory tests. The PET conditions complied with the regulations of the Ministry of Health of the Russian Federation and were approved by the ethical commission of the Institute of the Human Brain. All volunteers signed an informed consent to participation in the study.

We used a PC2048-15B scanner, which records 15 axial sections of the brain with a spatial resolution of 5–6 mm [22]. The temporal resolution (scan length, i.e., the period of data collection) was 60 s.

After the subject was instructed and began performing the task, 1.5 ml of water containing radioactive oxygen-15 (half-life 123 s, dose 0.86 mCi/kg) were injected through a catheter premounted in the ulnar vein. When a sufficient amount of the label was transferred into the brain (15–20 s after injection), brain scanning started automatically. Stimulus presentation began 10 s prior to the injection (i.e., 25–30 s before data collection) and continued for 10–15 s after data collection to exclude effects associated with the beginning or termination of task performance. The subject was unaware of the beginning and end of scanning. The interval between scanning periods was 15–20 min. The room was quiet, and illumination was maintained at the necessary minimum. The subject was instructed to lie relaxed in a comfortable position, to concentrate on the task, and to move only the fingers of the right hand to click the computer mouse buttons.

Since we were interested in relative changes in circulation in the brain, the study was limited to recording the isotope distribution without blood sampling, as in [23].

After reconstruction, PET images were analyzed using statistical parametric mapping (SPM99), which is a standard method employed in the analysis of physiological PET data [24] and demonstrates activation zones, i.e., areas of blood circulation more intense in one than in another (control) state. It should be noted, however, that such activation data do not provide any information on the prevalence of excitation or inhibition in the area under study [25].

As a result of pairwise comparisons of PET scans, we obtained difference images, which are known as

maps of the *t*-statistic distribution and reflect the difference established for each scan element (voxel). The significance of differences was assessed with a cluster size test [26]. Activation was considered significant when the size of the corresponding cluster (i.e., in our case, the number of adjacent voxels with $t > 3.90$) met the threshold requirement $P_{\text{corr}} < 0.05$. This threshold corresponds to the probability of a similar or larger cluster arising occasionally (i.e., in the absence of any signal) in the same space (i.e., in the brain) adjusted for the expected number of such clusters.

To determine the anatomical location of the activated area, we used the Talairach Space Utility program for coordinate conversion and cluster visualization (available at http://www.ihb.spb.ru/~pet_lab/TSU/TSUMain.html) and an electronic version of the Talairach Daemon atlas of the brain [27] (available at <http://ric.uthscsa.edu/projects/talairachdaemon.html>).

Auditory and visual stimuli were presented respectively via headphones and on the monitor screen (white on a dark background), which was located at the center of the subject's visual field. Test and control auditory stimuli were phrases with or without syntagmatic splitting, respectively (see the examples of the tasks). The phrases were read monotonously by a professional female speaker and subjected to digital processing to standardize the amplitude characteristics (by average RMS power) and meaningful pauses (110 ± 10 ms) and to minimize the meaningless pauses without loss of naturalness of the sound. Each phrase sounded for 2–3 s. In each task series, we used 30 phrases, which were not repeated in other series.

A question and several variants of the answer appeared on the screen, and a phrase was delivered 200–600 ms later. The interval between presentations of the visual and auditory stimuli was random to diminish the expectation effect. Having listened to the phrase, the subject clicked the corresponding button of the mouse, and a cross appeared on the screen to fix the gaze. After this, a question and variants of the answer for the next phrase were presented on the screen (Fig. 1). For each phrase, we recorded the variant of the answer selected by the subject and the reaction time.

The test protocol was developed after preliminary studies with 12 other subjects without PET scanning. Basing on the results of the preliminary behavioral studies, we selected phrases with a percentage of erroneous answers of no more than 25%. All phrases were tested for phonation adequacy at the Department of Phonetics of St. Petersburg State University.

To assess the possible emotional response of subjects to the differences in task complexity, the preliminary studies included recordings of the galvanic skin response (GSR) and heart rate (HR) during execution of each task.

Before PET recording, each subject was trained to execute the tasks with a set of phrases that were not used during scanning.

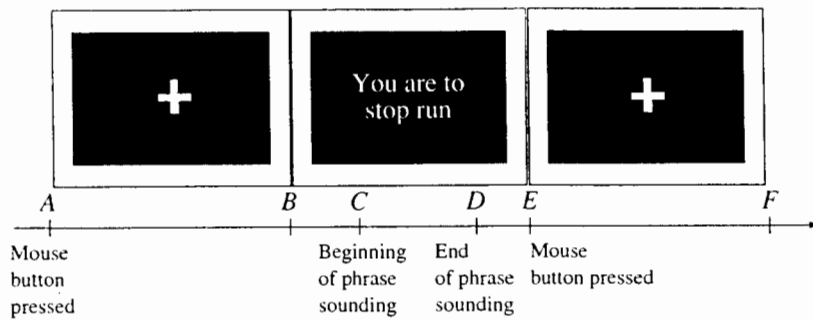


Fig. 1. Relationships between the duration of auditory and visual stimuli. Time intervals: *AB* and *EF*, presentation of a cross for gaze fixation, 300 or 600 ms; *BC*, presentation of a visual stimulus without an auditory one, 200–600 ms; *CD*, auditory stimulus; *DE*, selection of the correct answer by the subject.

The program Presentation (Neurobehavioral Systems) was used to present the stimuli and to record errors and the reaction time.

Four tasks were used in the study. For statistical analysis, two scans were obtained for each task; i.e., eight scans were obtained for each subject. For pseudorandomization, tasks were presented to subjects in the following order: 12344321, 23411432, 34122143, etc. In each PET examination, the subject executed the first task without scanning to avoid the first-scan effect [28].

Task 1. Phrases with syntagmatic splitting were presented binaurally. For distraction, the subject was requested to press one key when the phrase contained a word beginning with D and another key when there was no such word. For example, the phrase was “Don’t take, give” (“Brat’ nel’z’ya, davat’” in Russian), and the screen read “A D word is present/absent.”

Task 1C (control to task 1). Phrases without syntagmatic splitting were presented. The instructions were as in task 1. For example, the phrase was “It was warm in the room” (“V komnate bylo teplo” in Russian), and the screen read “A D word is present/absent.”

Task 2. Phrases with syntagmatic splitting were binaurally presented. Unlike task 1, the subject was requested to choose the variant matching the phrase from two variants presented on the screen and to press the corresponding key. For example, the phrase was “Don’t run, stop” (“Bezhat’ nel’z’ya, stoyat’” in Russian). The screen read “You are to stop/run.” Or the phrase was “Petr, said Ivan” (“Petr, skazal Ivan” in Russian), and the screen read “Who said? Ivan/Petr”

Task 2C (control to task 2). Phrases without syntagmatic splitting were presented. The instructions were as in task 2. For example, the phrase was “Father bought him a coat” (“Otets kupil emu pal’to” in Russian). The screen read “The father bought him a coat/a watch.”

We expected that comparisons between the test and corresponding control states would reveal the following cognitive operations:

changes in activity of the system for automatic analysis of the prosodic properties of vocal stimuli (comparison 1 minus 1C) and

changes in activity of the system for conscious analysis of the prosodic properties of vocal stimuli (comparison 2 minus 2C).

RESULTS

Analysis of the data obtained in preliminary behavioral studies yielded the following results.

No significant differences in reaction time and percentage of errors were found between tasks 1 and 1C with the *t*-statistics ($P < 0.01$). Likewise, there were no significant differences in percentage of errors between tasks 2 and 2C ($P < 0.01$) (table).

Assessment of the data on changes in GSR and HR with the *t*-statistics in the preliminary study did not reveal significant ($P < 0.01$) differences between the test and control states.

The following results were obtained in PET data comparisons demonstrating the cognitive components under study (Figs. 2, 3).

No activation zones were found for the unconscious (automatic) analysis of phrases with syntagmatic splitting (comparison 1 – 1C). Likewise, the inverse comparison 1C – 1 did not reveal any significant differences.

Comparison 2 – 2C, which reflects conscious analysis of phrases with syntagmatic splitting, revealed an activation zone in the right medial and lower frontal convolutions; the zone mostly involved Brodmann’s areas (BAs) 44, 45, and 9. Another activation zone was located in the posterior medial area of the right hemisphere of the cerebellum (Fig. 2).

In addition, we found areas where blood circulation was higher in task 2C than in task 2. In the right hemisphere, such an area was located deep inside the posterior half of the perisylvian cortex and involved the auditory cortex and the islet (BAs 41, 42, 13). An almost symmetrical area found in the left hemisphere was larger, extending forward to the temporal and insular

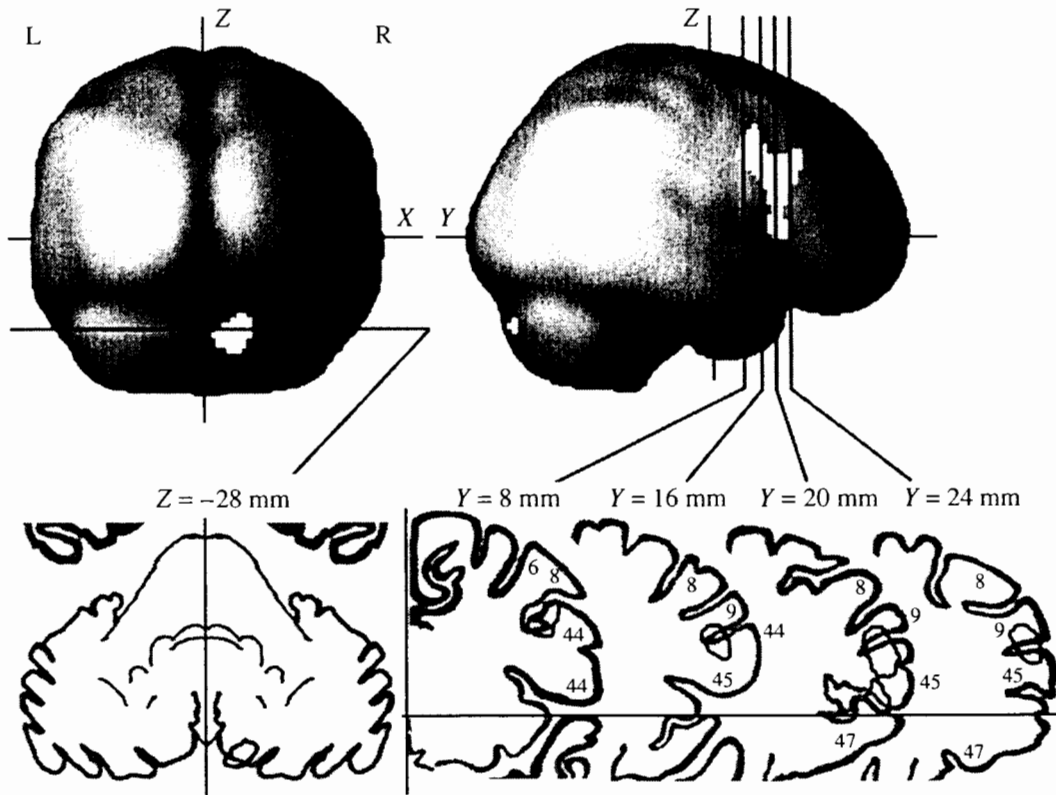


Fig. 2. Activation zones associated with conscious analysis of phrases with syntagmatic splitting as revealed by comparison 2 – 2C. Projections of the activation areas onto the posterior and right surfaces of a smoothed “standard” brain are shown in the stereotactic system [26], which is defined by three axes: X, Y, and Z. The location of the activation zones is shown in more detail in the lower part of the figure, on horizontal (for the cerebellum) and coronal (for the right hemisphere) sections. Here and in Fig. 3: numbers indicate the nearest Brodmann’s areas. The X and Y coordinates of the sections are indicated. Contours of brain structures and localization of the Brodmann’s areas are as in the atlas [26]. L, left hemisphere; R, right hemisphere.

cortex (BAs 41, 42, 22, 13), as well as to the posterior parietal cortex (BA 40) (Fig. 3).

DISCUSSION

Theoretically, the differences observed in PET patterns of brain activation could be a consequence not only of specific cognitive differences between the tasks used in this study, but also of nonspecific factors reflecting, for example, differences in the task complexity. A difference in mean reaction time between the test and

control tasks could hardly be an objective index of task complexity effects, because prolongation of the reaction time in the test versus the control task was rather caused by an additional cognitive component. On the other hand, a difference in the percentage of errors may serve as a more reliable index of a greater nonspecific difficulty of test tasks as compared with control tasks. However, we found no significant difference in this index (table), evidencing that differences in task complexity had no effect on differences in PET activity patterns. Indirect evidence for this was also provided by preliminary studies, which revealed no significant alterations in GSR and HR between the test and control states.

No significant changes were revealed by comparisons characterizing the unconscious analysis of syntagmatic splitting (comparisons 1 – 1C and 1C – 1). This is probably explained by the fact that differences in activation between the two corresponding conditions were very small, beyond the threshold set by the statistical test applied. However, conscious execution of a similar task, with the choice of the answer depending directly on the phrase splitting (task 2), signifi-

Task performance in the preliminary study

Task	Mean reaction time, s ($P < 0.01$)	Mean percentage of errors ($P < 0.01$)
1	3.3 ± 0.09	12 ± 3
1C	3.3 ± 0.2	11 ± 2
2	3.8 ± 0.1	15 ± 4
2C	2.8 ± 0.07	16 ± 5

Note: Mean, confidence interval, and significance are presented for reaction time and percentage of errors.

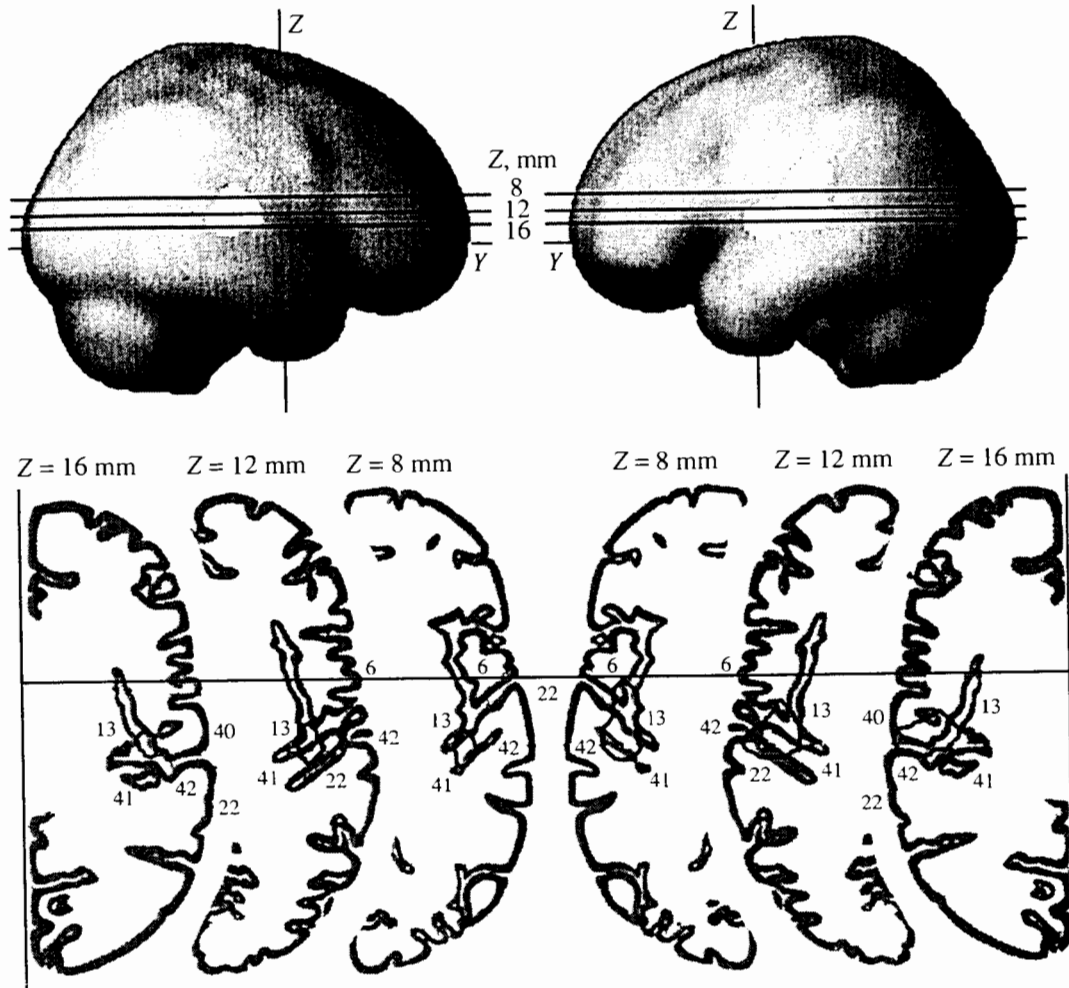


Fig. 3. Areas of higher blood circulation in state 2C, as found with comparison 2C – 2. Projections of the areas onto the surfaces of the hemispheres are shown along with their precise localization on horizontal sections of the brain.

cantly increased the corresponding activation (comparison 2 – 2C).

Activation of the right lower frontal area and a zone of the right hemisphere of the cerebellum during the conscious processing of phrases with syntagmatic splitting most probably reflects analysis of the semantic and phonetic characteristics isolating a syntagma.

From the formal phonetic viewpoint, a syntagma is an array of words integrated in a single intonation pattern. The splitting of speech into syntagmas is achieved by two mechanisms. One mechanism relies on the separating role of the pause between syntagmas. Another is based on the differences in pitch between the end of the syntagma preceding the pause and the beginning of the next syntagma [29].

Probably, the right lower frontal cortex is involved in analyzing the intonation factor, which is supported by works demonstrating its role in pitch analysis [30, 31]. In addition, this explains the role of the right prefrontal area in perception of both linguistic (in our study) and emotional [19, 32] prosody.

The activation revealed in the right hemisphere of the cerebellum by comparison 2 – 2C could be associated with assessment of another important parameter of syntagmatic splitting, namely, a pause between syntagmas. The cerebellum is often considered as a key structure involved in the assessment of time intervals, which is necessary for many kinds of sensorimotor and cognitive activity [33, 34]. In addition, the right hemisphere of the cerebellum is morphologically (via the thalamic nuclei) and functionally linked with the contralateral frontal cortex, including Broca's area [35, 36].

It is also possible that the role of the activation of the right hemisphere of the cerebellum is associated with assessment of phonetic and semantic relationships taking place within syntagmas and changing at their margins or with the maintenance of phrase structure in the working memory during such analysis [36]. The phrases with syntagmatic splitting used in task 2 probably require more from the corresponding brain systems than the phrases used in control task 2C.

Syntagmatic splitting of phrases assessed acoustically makes it possible to infer their syntactic structure. In visual presentation of sentences, this is achieved with punctuation. We hypothesize that common brain mechanisms serve in syntax analysis regardless of the mode of presentation. However, studies of syntax analysis of sentences presented visually revealed a dominance of the left hemispheric structures in this process [37–41]. In this work, we did not find appreciable activations in the left hemisphere according to comparison 2 – 2C. A possible explanation is that stimuli presented in the control task were words organized into phrases, rather than separate words as in other studies, although the phrases were syntactically simpler than in the test task.

The increase in blood circulation in the left perisylvian cortex that was observed in task 2C as compared with task 2 may be associated either with suppression of the functional activity of the relevant areas in task 2 or with their activation in control task 2C. It is possible that analysis of phrases lacking a splitting pause activates a different neuronal system including the parietal, auditory, and insular cortex. On the other hand, these activations may be associated with the acoustic difference between phrases containing or lacking pauses, which, in turn, may cause a higher activation of the auditory cortex and the adjacent areas in task 2C as compared with task 2.

CONCLUSIONS

We showed that conscious analysis of the effect of a splitting pause on the semantic structure of a phrase is accompanied by functional activation of the lower right prefrontal area and the posterior medial area of the right hemisphere of the cerebellum. On the other hand, a similar task involving unconscious analysis was not accompanied by appreciable local activations, suggesting a mechanism increasing the activation of the relevant brain areas in conscious (metalinguistic) analysis of phrases. Comparison of our results with published data points to a significant difference in brain systems responsible for syntactic analysis of verbal stimuli differing in mode of presentation.

ACKNOWLEDGMENTS

We are grateful to the staff of the PET and radiochemistry laboratories for assistance and to Prof. N.D. Svetozarova (Department of Phonetics, St. Petersburg State University) for help in phrase preparation. This study was supported by the Russian Foundation for Humanitarian Research (project no. 03-06-00206) and the Russian Foundation for Basic Research (project nos. 00-15-97893, “The Scientific School of Academician N.P. Bechtereva,” and NSh-1921.2003.4, “The St. Petersburg School of Psycholinguistics”).

REFERENCES

1. Van Lancker, D., Canter, G. J., and Terbeek, D., Disambiguation of Ditropic Sentences: Acoustic and Phonetic Cues, *J. Speech Hearing Res.*, 1981, vol. 24, no. 3, p. 330.
2. Toga, A.W. and Thompson, P.M., Mapping Brain Asymmetry, *Nat. Rev. Neurosci.*, 2003, vol. 4, no. 1, p. 37.
3. Robin, D., Tranel, D., and Damasio, H., Auditory Perception of Temporal and Spectral Events in Patients with Focal Left and Right Cerebral Lesions, *Brain Lang.*, 1990, vol. 39, no. 4, p. 539.
4. Alpherts, W.C.J., Vermeulen, J., Franken, M.L.O., *et al.*, Lateralization of Auditory Rhythm Length in Temporal Lobe Lesions, *Brain Cognition*, 2002, vol. 49, no. 1, p. 114.
5. Gandour, J., Wong, D., and Hutchins, G., Pitch Processing in the Human Brain Is Influenced by Language Experience, *NeuroReport*, 1998, vol. 9, no. 9, p. 2115.
6. Van Lancker, D., Cerebral lateralization of Pitch Cues in the Linguistic Signal, *Int. J. Hum. Comm.*, 1980, vol. 13, no. 7, p. 201.
7. Blumstein, S. and Cooper, W.E., Hemispheric Processing of Intonation Contours, *Cortex*, 1974, vol. 10, no. 2, p. 146.
8. Ross, E. D. and Mesulam, M.M., Dominant Language Functions of the Right Hemisphere: Prosody and Emotional Gesturing, *Arch. Neurol.*, 1979, vol. 36, no. 3, p. 144.
9. Bottini, G., Corcoran, R., Sterzi, R., *et al.*, The Role of the Right Hemisphere in the Interpretation of Figurative Aspects of Language: A Positron Emission Tomography Activation Study, *Brain*, 1994, vol. 117, no. 6, p. 1241.
10. Walker, J. P., Fongemie, K., and Daigle, T., Prosodic Facilitation in the Resolution of Syntactic Ambiguities in Subjects with Left and Right Hemisphere Damage, *Brain Language*, 2001, vol. 78, no. 2, p. 169.
11. Buchanan, T.W., Lutz, K., Mirzazade, S., *et al.*, Recognition of Emotional Prosody and Verbal Components of Spoken Language: An fMRI Study, *Cogn. Brain Res.*, 2000, no. 9, p. 227.
12. Emmorey, K.D., The Neurological Substrates for Prosodic Aspects of Speech, *Brain Language*, 1987, vol. 30, no. 2, p. 305.
13. Grela, B. and Gandour, J., Locus of Functional Impairment in the Production of Speech Rhythm after Brain Damage: A Preliminary Study, *Brain Language*, 1998, vol. 64, no. 3, p. 361.
14. Chernigovskaya, T., Svetosarova, N., and Tokareva, T., Hemispheric Contributions to Processing Affective and Linguistic Prosody, *Proc. 13th Int. Congr. of Phonetic Sciences*, Stockholm, 1995, p. 494.
15. Chernigovskaya, T.V., Svetozarova, N.D., Tokareva, T.I., *et al.*, Specialization of Brain Hemispheres in the Perception of Russian Language Intonations, *Fiziol. Chel.*, 2000, vol. 26, no. 2, p. 24.
16. Ross, E.D., Thompson, R.D., and Yenkosky, J., Lateralization of Affective Prosody in Brain and the Callosal Integration of Hemispheric Language Functions, *Brain Language*, 1997, vol. 56, no. 1, p. 27.
17. Steinhauer, K., Alter, K., and Friederici, A., Brain Potentials Indicate Immediate Use of Prosodic Cues in Natural

- Speech Processing, *Nat. Neurosci.*, 1999, vol. 2, no. 2, p. 191.
18. Hayashi, R., Imaizumi, S., Mori, K., *et al.*, Elicitation of N400m in Sentence Comprehension due to Lexical Prosody Incongruity, *NeuroReport*, 2001, vol. 12, no. 8, pp. 1753.
 19. Gandour, J., Wong, D., Hsieh, L., *et al.*, Crosslinguistic PET Study of Tone Perception, *J. Cogn. Neurosci.*, 2000, vol. 12, no. 1, p. 1.
 20. Raichle, M.E., Quantitative *In Vivo* Autoradiography with Positron Emission Tomography, *Brain Res.*, 1979, vol. 180, p.47.
 21. Oldfield, R.C., The Assessment and Analysis of Handedness: The Edinburgh Inventory, *Neuropsychologia*, 1971, vol. 9, no. 1, p.97.
 22. Holte, S., Eriksson, L., and Dahlbom, M., A Preliminary Evaluation of the Scanditronix PC2048-15B Brain Scanner, *Eur. J. Nuc. Med.*, 1989, vol. 15, p. 719.
 23. Fox, P.T., Mintun M.A., Raichle M.E., and Herscovitch, P., A Non-Invasive Approach to Quantitative Functional Brain Mapping with H2[15]O and Positron Emission Tomography, *J. Cereb. Flow Metab.*, 1984, vol. 4, no. 3, p. 329.
 24. Friston, K.J., Statistical Parametric Mapping and Other Analyses of Functional Imaging Data, *Brain Mapping: The Methods*, Toga, A.W. *et al.*, Eds., Academic, 1996, p. 363.
 25. Jueptner, M. and Weiller, C., Review: Does Measurement of Regional Cerebral Blood Flow Reflect Synaptic Activity?—Implication for PET and fMRI, *Neuroimage*, 1995, vol. 2, p.148.
 26. Worsley, K.J. Poline, J.B., Frakowiak R.S.L., and Friston, K.J., Test for Distributed, Non-Focal Brain Activation, *Neuroimage*, 1995, vol. 2, p. 183.
 27. Talairach, J. and Tournoux, P., *Co-Planar Stereotaxic Atlas of the Human Brain*, Stuttgart: Georg. Thieme, 1988.
 28. Rajah, M.N., Hussey, D., Houle, S., *et al.*, Task-Independent Effects of Time on rCBF, *Neuroimage*, 1998, no. 7, p. 314.
 29. Svetozarova, N.D., Syntagma, in *Lingvisticheskii entsiklopedicheskii slovar'* (Encyclopedia of Linguistics), Moscow: Soverskaya Entsiklopediya, 1990, p. 447.
 30. Zatorre, R., Evans, A., Meyer, E., and Gjedde, A., Lateralization of Phonetic and Pitch Processing in Speech Perception, *Science*, 1992, vol. 256, p. 846.
 31. Klein, D., Zatorre, R. J., Milner, B., and Zhao, V., A Cross-Linguistic PET Study of Tone Perception in Mandarin Chinese and English Speakers, *Neuroimage*, 2001, vol. 13, no. 4, p. 646.
 32. George, M.S., Parekh, P.I., Rosinsky, N., *et al.*, Understanding Emotional Prosody Activates Right Hemisphere Regions, *Arch. Neurol.*, 1996, vol.53, no. 7, p. 665.
 33. Salman, M.S., The Cerebellum: It's about Time! But Timing is not Everything—New Insights into the Role of the Cerebellum in Timing Motor and Cognitive Tasks, *J. Children Neurol.*, 2002, vol. 17, no. 1, p. 1.
 34. Ivry, R.B. and Richardson, T.C., Temporal Control and Coordination: The Multiple Timer Model, *Brain Cognition*, 2002, vol. 48, no. 1, p. 17.
 35. Engelborghs, S., Marten, P., Martin, J.J., and De Deyn, P.P., Functional Anatomy, Vascularisation and Pathology of the Human Thalamus, *Acta Neurol. Belg.*, 1998, vol. 8, no. 3, p. 252.
 36. Marien, P., Engelborghs, S., Fabbro, F., and De Deyn, P.P., The Lateralized Linguistic Cerebellum: A Review and a New Hypothesis, *Brain Language*, 2001, vol. 79, no. 3, p. 580.
 37. Caplan, D., Alpert, N., and Waters, G., PET Studies of Syntactic Processing with Auditory Sentence Presentation, *Neuroimage*, 1999, vol. 9, p. 343.
 38. Indefrey, P., Hagoort, P., Herzog, H., *et al.*, Syntactic Processing in Left Prefrontal Cortex is Independent of Lexical Meaning, *Neuroimage*, 2001, vol. 14, no. 3, p. 546.
 39. Roder, B., Stock, O., Neville, H., *et al.*, Brain Activation Modulated by the Comprehension of Normal and Pseudo-Word Sentences of Different Processing Demands: A Functional Magnetic Resonance Imaging Study, *Neuroimage*, 2001, vol. 15, no. 4, p. 1.
 40. Roder, B., Stock, O., Neville, H., *et al.*, Brain Activation Modulated by the Comprehension of Normal and Pseudo-Word Sentences of Different Processing Demands: A Functional Magnetic Resonance Imaging Study, *Neuroimage*, 2002, vol. 15, no. 4, p. 1003.
 41. Vorob'ev, V.A., Medvedev, S.V., and Pakhomov, S.V., A Study of Brain System of Involuntary Syntactic Processing using Positron Emission Tomography, *Fiziol. Chel.*, 2000, vol. 26, no. 4, p. 5.