

Neurophysiological Analysis of Speech Perception in 2.5 to 3.5-Year-Old Orphans and Children Raised in a Family

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In 2.5-3.5-year-old orphans ($n = 41$) and children raised in a family ($n = 50$), we examined specificities of speech perception-related changes in the spectral power density (SPD) of the EEG rhythms. Changes in the SPDs of the θ -, α -, β -, and γ -rhythms in 16 EEG leads were estimated at presentation of a meaningful speech fragment record (short poem) and of a reversed record of the same signal (direct and reversed speech, respectively). The Bayley Scales of Infant and Toddler Development III demonstrated the existence of noticeable delays in the development of speech in orphans. Comparison of background EEGs and EEGs in the course of listening for direct speech showed that the α -rhythm is desynchronized, while the θ -, β -, and, especially, γ -oscillations are synchronized upon perception of the above stimulus. In this case, children raised in a family demonstrated significant increases in the γ -rhythm SPD in 13 leads of both hemispheres; in orphans, this was observed only in 8 loci localized mostly in the left hemisphere. In children of both groups, listening for reversed speech induced mostly desynchronization of all EEG rhythms with the greatest drops in the γ SPD mostly in the frontal and left temporal leads. Comparison of SPDs of the EEG components (rhythms) at listening for direct and reversed speech demonstrated that powers of θ -, β -, and γ -oscillations increased at presentation of a direct (comprehended) speech in children of both groups. In children raised in families, greater SPDs of the γ -rhythm were observed in 13 leads (differences were most significant in the frontal parts of the left hemisphere). In institutionalized children, the number of leads with significant increments of the γ -rhythm power was significantly smaller (only 9). It is supposed that smaller increases in the SPD of γ -range oscillations in orphans are related to deviations in the processing of a semantic component of speech perception. This can result from insufficient development of cerebral neuronal networks responsible for processing of verbal information.

Keywords: speech perception, EEG rhythms, orphans, direct and “reversed” speech

INTRODUCTION

Human speech is a unique phenomenon because it supports not only interindividual and social communications but also storing of information and the process of thinking itself. Electroencephalographic techniques are extensively used in the studies of neurophysiological mechanisms of perception and generation of speech. In a number of studies, it was shown that the main EEG rhythms change significantly upon listening to speech and preparation for one's own verbal utterance.

Processes of language development in children attract special attention. The level of mastering of speech perception and speech generation by a child is a most important index characterizing the level of his/her cognitive and social development. The child's language abilities develop through his/her interaction with the parents and other significant adults. Considering that a large number of children in the world in general and of Ukrainian children in particular are deprived of communication with their parents (as they are raised in residential care institutions), the analysis of neurophysiological mechanisms of speech perception in such children is especially urgent and important.

Delays in physical and cognitive development, including that of the speech sphere, are frequently observed in orphans growing up in residential care institutions [2, 3]. It is believed that delays in the language development in orphans are determined by disorders of child/parent relations and by the

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absence or insufficiency of communications with a significant adult during the early years of life [4]. Language and cognitive delays persist for a long time even after adoption. Taking this fact into account, it should be supposed that the development of the CNS and, first of all, of the neocortex is significantly disturbed in such children. The above disorders are believed to be related to slowing down of the processes of growth of neurons and formation of neuron-to-neuron connections and to delays in myelination of the respective axons [5, 6]. Deviations in the CNS development are reflected in the pattern of ongoing EEG of adopted children [7]. Tarullo et al. [6] examined EEG activity of 1.5-year-old children adopted from orphanages. As was found, the spectral power densities (SPDs) of ongoing EEGs of orphans measured within the frequency bands of the α - and β -rhythms were significantly lower than those in children raised in families. The authors concluded that lower SPDs of the above-mentioned rhythms reflect some delays in brain development.

Development of the speech comprehension ability is one of the key elements in general development of the child's language [8]. The most rapid development of the ability of a child to perceive entire verbal messages occurs between 2.5 and 3.5 years [9]. Benasich and Gou demonstrated the relation between the SPD of the EEG γ -rhythm in 2- to 3-year-old children and adequacy of processing of the semantic speech content at the 4-year age [10]. A technique developed by Krause et al. [11] is one of the approaches in the studies of neurophysiological mechanisms of speech perception based on the analysis of EEG patterns. Two types of stimuli, one of which was a record of the semantically meaningful speech sample (direct speech), while another corresponded to the same record but reproduced in a reversed mode (reverse speech), were presented. Therefore, the second stimulus was a speech-like signal similar in many characteristics to direct speech but deprived of any semantic content. The use of this method allowed researchers to estimate the level of the corresponding synchronization/desynchronization of the EEG rhythms and to conclude that neurophysiological mechanisms of speech perception include two key components. The first component is related to perception of any speech-like acoustic signal, while the second one is related to perceiving the meaning of the proposed speech sample. Studies of speech perception using the Krause's technique, as we know, were carried

out only on adult subjects.

Considering all the above mentioned, we tried to analyze neuro- and psycho-physiological mechanisms of speech perception in institution- and family-raised children (age from 2.5 to 3.5 years). Such analysis was based on examination of EEG patterns at presentations of direct and reverse speech. The above-mentioned age interval was selected because, as was mentioned, it corresponds to the period of most rapid development of the ability of children to perceive entire verbal messages.

METHODS

Ninety-one children took part in the tests. The main group was formed from social orphans recruited from the children's residence care institution "Yolochka," Simferopol' ($n = 41$, 27 boys and 14 girls, age from 30 to 41 months, mean age 36 ± 2 months). The control group included children from complete families ($n = 50$, 31 boys and 19 girls, age from 29 to 42 months, mean age 35 ± 3 months). Children with the birth body mass below 2.5 kg, with genetic diseases, and with medical records of CNS diseases and/or fetal alcoholic syndrome, and also sinistrals (children drawing by the left hand) were not included in the examined groups. Orphans who spent less than one year at the institution were also excluded from the main group. Information on the correspondence of our study to the existing international ethic norms is presented in the respective paragraph (see below).

Recording of EEG was carried out in three test situations: (i) Recording of ongoing EEG of the child in the relaxed state with the eyes open (60-sec-long background record); (ii) recording of EEG at listening for direct speech (as a speech stimulus, we used reproduction of the sound record of a short poem with content understandable to the child; duration 20 sec), and (iii) recording of EEG at listening for the record of the same poem but reversed using a computer program (20-sec-long reverse speech). The reversed record corresponded by its physical characteristics and acoustic composition of the direct speech signal but was meaningless. During presentation of the auditory signals, the tested children were at a 2-3 m distance from loudspeakers, and the sound volume corresponded to 75 dB above the audibility threshold. The second and third situations were alternated in a randomized mode.

Electroencephalograms were recorded using a digital telemetric electroencephalograph "Tredex" (Ukraine). Processing and analysis of EEG was performed with the help of "EEG Mapping 6" software developed in the laboratory of neuroethology of the Tavricheskii National University (programmer Ye. N. Zinchenko). Electrodes were localized in Fp1, Fp2, F3, F4, F7, F8, C23, C4, T3, T4, T5, T6, P3, P4, O1, and O2 sites according to the international 10-20 system. A special 16-channel electrode cap "Polina" for children ("Tredex," Ukraine) with built-in Ag–AgCl electrodes was used. All interconnected electrodes except the active one served as a reference electrode. A neutral (grounding) electrode was positioned between leads C3 and C4. Frequency cuts of the filters were 1.5 and 48 Hz, and the frequency of digitization of EEG signals was 250 sec^{-1} .

Records of EEG samples for each experimental situation were processed independently from each other; epochs containing artifacts were detected by visual inspection, and movement-related artifacts were eliminated. EEG samples obtained from some children and containing numerous artifacts were also eliminated from the general sampling. The signals were processed using fast Fourier transforms and smoothing by the Blackman technique. We measured values of the spectral power density (SPD, $\mu\text{V}^2/\text{Hz}$) within the following frequency ranges: θ (4-6 Hz) [7, 12], α (7-10 Hz) [7, 13], β (11-29 Hz) [12, 14], and γ (30-45 Hz) [10, 12]. The δ -rhythm was not analyzed in this study as its oscillation frequency overlapped with movement-related artifacts.

Children's language development was assessed using the Language scale of the Bayley Scales of Infant and Toddler Development III (BSID-III) [15]. According to the instruction of this test, a set of tasks was presented to the child; the complexity of the tasks varied according to the age. The task completion level allowed us to estimate the adequacy of speech understanding by the child, development of expressive speech, etc. Independently of the age, the child could get from 55 to 145 points on the respective scales. According to the Bayley test, the normal variance of language development spreads from 90 to 110 points.

Tests were carried out during two days, at a time convenient for the children (for those from the institution, after a breakfast). Within the first day, the child was subjected to the entire psychological testing using the Bayley III system. In this paper,

we analyze data related exclusively to the speech scales. The EEG recording was performed within the second day. The duration of preliminary procedures (positioning of the electrodes) and EEG recording (including that at presentation of the speech stimuli and at other experimental situations that are not analyzed in this paper) did not exceed 10 min. The total duration of the entire testing within two days did not exceed 40 min.

Numerical data of psychological and electrophysiological examinations were processed using standard techniques of variation statistics. Distributions of the data in a few cases differed from the normal one; this is why we used nonparametric criteria of comparison. The significance of intergroup differences was estimated using the Mann–Whitney test; comparison of SPD values of the EEG rhythms in various experimental situations was carried out according to the Wilcoxon test. For graphic presentation of EEG reactions, we calculated the coefficient of evoked synchronization/desynchronization (ESD), as was proposed by a few authors [11, 16]. For each frequency range in each of the leads used, the ESD coefficients were calculated according to the formula $\text{ESD} = (S - F) / F$, where S is the mean SPD of this EEG rhythm upon the action of the stimulus (second or third experimental situation), and F is the mean SPD of this rhythm in the ongoing EEG with the eyes open (first situation). Besides this, differences between the SPDs of the rhythms under conditions of perception of direct and reverse speech were estimated using the same method. Levels of SPDs of the EEG rhythms at perception of reverse speech were considered background values in this case. Values of the $\text{ESD} > 0$ were indicative of synchronization of EEG oscillations, i.e., of a rise in the SPD, as compared to that in the background record, while $\text{ESDs} < 0$ showed that oscillations of this rhythm in this lead were desynchronized (i.e., the SPD of this frequency range decreased).

RESULTS

The Bayley assessment showed that children raised in the orphanage were characterized by noticeable delays in language development, as compared with the respective level in the group of children raised in families. Institutionalized children demonstrated lower results both on Receptive and on Expressive communication scales. For these

children, the mean estimate of speech understanding corresponded to 86.3 ± 15.5 , while in children of the control group this value was 107.5 ± 13.5 scores (the difference is significant at $P = 0.048$). In children of the institutionalized group, the mean result of testing based on the scale of speech generation was 82.7 ± 14.5 , while in children of the control group this estimate was 101.8 ± 16.0 scores ($P = 0.032$; $\bar{x} \pm s.d.$ values are shown).

Diagrams illustrating the process of synchronization/desynchronization of EEG oscillations in children of the institutionalized and control groups are shown in Fig. 1. In the control group of children, increases in the SPD within the θ -, β -, and γ -frequency ranges, as compared with the SPDs of the above rhythms in ongoing EEGs under conditions of the eye-opened resting state, were the most typical reaction during the perception of direct speech. In particular, statistically significant SPD increases (synchronization) of the θ -rhythm were found in the posteriorfrontal, temporal, and parietal leads of the left hemisphere and in the central and anterior temporal leads of the right hemisphere. For the β -rhythm, significant synchronization was observed mostly in the posteriorfrontal and temporal

leads. Synchronization of the γ -rhythm was found in most leads (13 of 16) of both hemispheres. At the same time, desynchronization in the left posteriorfrontal and temporal leads was typical of the α -rhythm.

In the institutionalized group, listening for the direct speech stimulus also induced statistically significant SPD rises within frequency ranges of the θ -, β -, and γ -rhythms. This effect was, however, manifested in a noticeably smaller number of leads than in children of the control group. In particular, significant increases in the SPDs of the θ -rhythm were recorded in the anterior frontal and occipital leads of the left hemisphere and in the temporal lead of the right hemisphere. For the β -rhythm, such changes were noted in the anterior frontal, temporal, and occipital leads of the left hemisphere. Significant increases in the SPD of the γ -rhythm were found in half of the loci (8 from 16) localized mostly in the left hemisphere. Significant decreases in the α -rhythm SPDs were observed in the posterior frontal and occipital leads bilaterally and also in the temporal leads of the right hemisphere.

In both groups, desynchronization of all EEG rhythms was the typical reaction during listening to

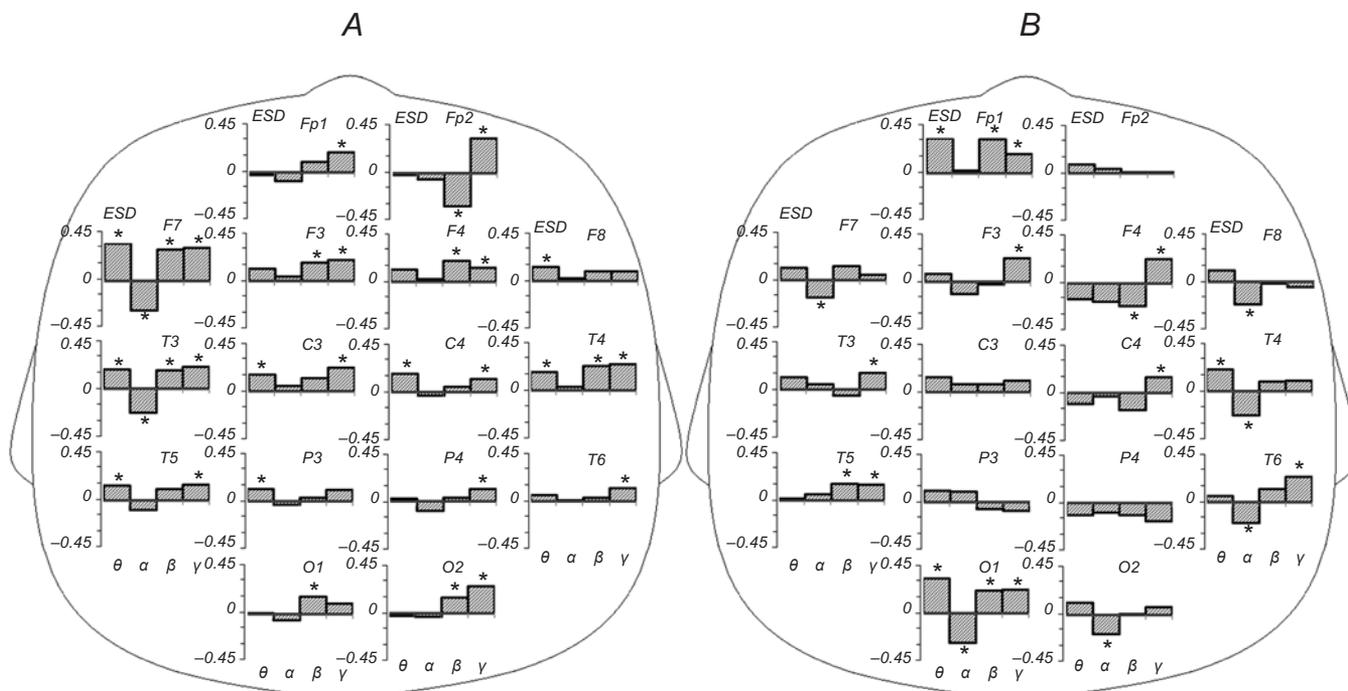


Fig. 1. Diagrams of the coefficients of changes in the spectral power density (SPD) of the EEG rhythms (evoked synchronization/desynchronization, ESD) induced by listening for direct speech, as compared to background SPD values, in children of the control (A) and main (B) groups. Each diagram corresponds to the definite recording locus. Horizontal axis) EEG rhythms (θ , α , β , and γ); vertical axis) values of the coefficient of ESD. Asterisks indicate cases of significant increases or decreases of the SPD of one rhythm or another, as compared to that in the background sample ($P < 0.05$).

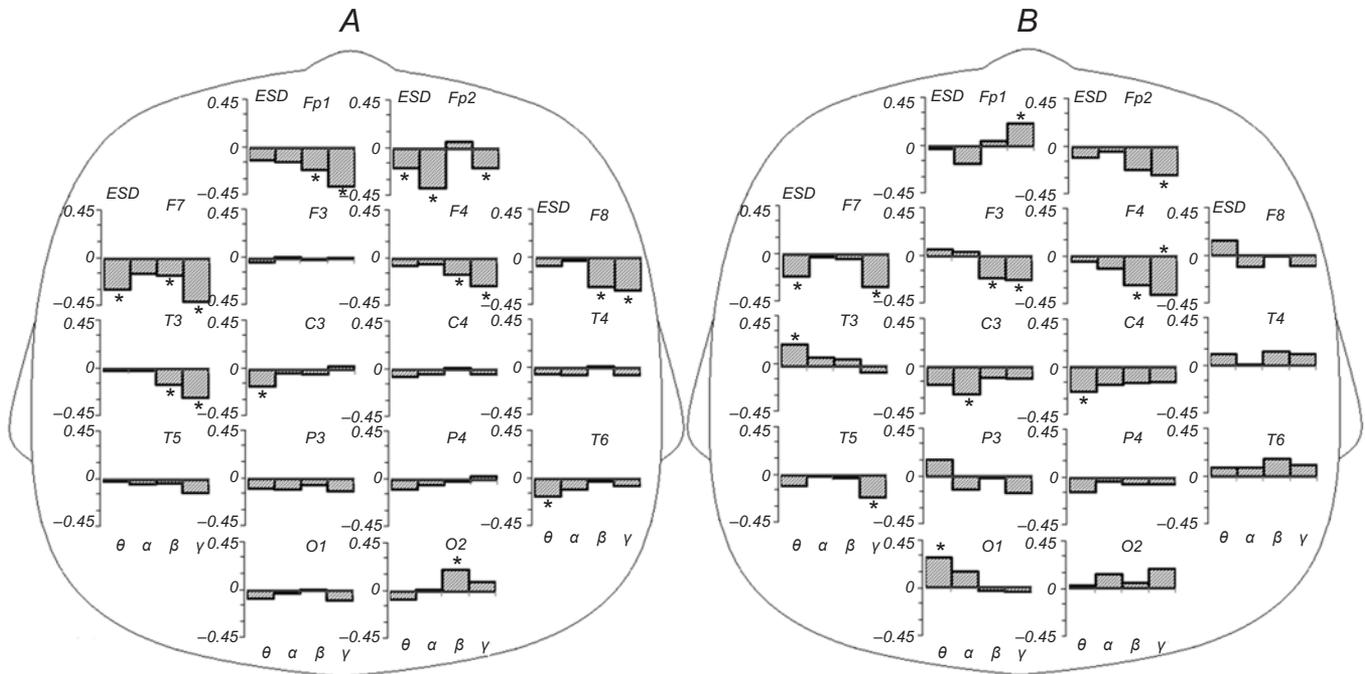


Fig. 2. Diagrams of the coefficients of changes in the spectral power density (SPD) of the EEG rhythms induced by listening for reverse speech, as compared to background SPD values, in children of the control (A) and main (B) groups. Other designations are similar to those in Fig. 1.

reverse speech (Fig. 2). In children of the control group, significant decreases in the θ -rhythm SPDs were recorded in the anterior frontal and posterior temporal leads of the right hemisphere and in the posterior frontal and central leads of the left hemisphere. The SPD of α -oscillations dropped considerably in the right anterior frontal lead. For the β -rhythm, SPD decreases were found in the left anterior and posterior frontal and anterior temporal leads; the same was found in the right frontal and anterior temporal leads. The γ -rhythm SPD decreased in the posterior temporal and anteriofrontal leads and also in the right frontal and left anterior temporal leads. A rather similar pattern of changes was observed in children of the institutionalized group. Significant decreases in the θ -rhythm SPD were detected in the right central and left posteriofrontal leads. At the same time, the SPD of this rhythm significantly increased in the left temporal and occipital leads. As to the α -rhythm, a significant decrease in the SPD was recorded only in lead C3, and for the β -rhythm this was observed in leads C3 and C4.

Diagrams of the coefficients reflecting changes in the SPDs of EEG rhythms upon listening for direct speech, as compared with the corresponding powers at presentation of reverse speech, in children of both

examined groups are shown in Fig. 3. The action of the speech signal containing meaningful information induced significant increases in the SPDs within the θ -, β -, and γ -ranges in both groups of children. In children of the control (family) group, perception of direct speech led to significant increases in the θ -rhythm SPDs in more than half of the leads (10 of 16). The α -rhythm was desynchronized under these conditions in the posterior frontal and temporal leads. Significant increases in the β SPDs occurred in the posterior frontal and anterior temporal leads, and also in the right frontal lead. The γ -rhythm powers increased in 13 of 16 leads. These rises were most intense ($P < 0.01$) in the left hemisphere, in the F7, Fp1, and F3 leads.

In orphans, patterns of synchronization/desynchronization of EEG during perception of direct and reverse speech were rather alike to the patterns demonstrated by the control group. At the same time, leads with significant differences of SPDs of the EEG rhythms in these two experimental situations were significantly fewer in the institutionalized group. Significant increments in the θ SPDs during perception of direct speech, as compared with the respective values at reverse speech, were observed only in the left posteriofrontal and central leads. Significant differences between the respective

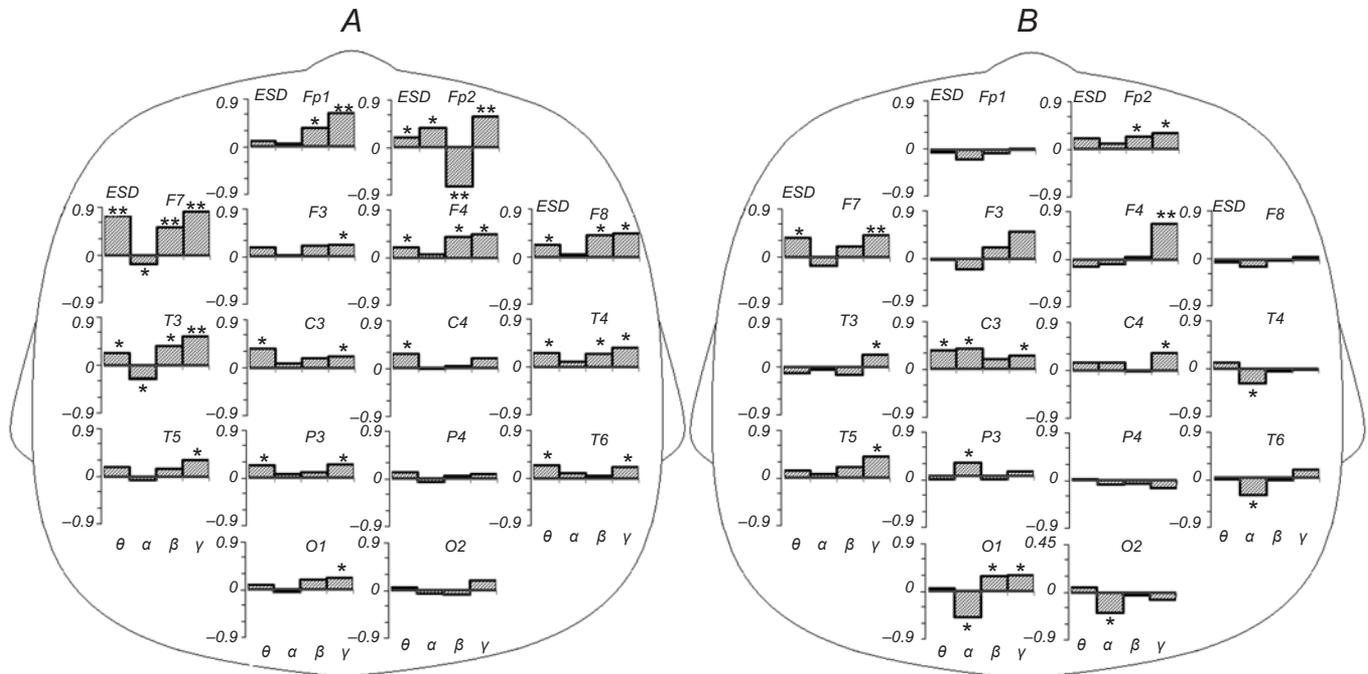


Fig. 3. Diagrams of the coefficients of changes in the spectral power density (SPD) of the EEG rhythms induced by listening for direct speech, as compared to corresponding SPD values at listening for reverse speech in children of the control (A) and main (B) groups. Two asterisks indicate cases of significant increments or decrements of the SPDs of the rhythms. Other designations are similar to those in Figs. 1.

SPDs of the α -rhythm were found in the occipital, right temporal, and left central and parietal leads. Differences of the β SPD reached the significance level only in the left occipital and right anterior frontal leads. Increases in the γ -rhythm SPDs related to perception of direct speech, as compared with the SPDs at reverse speech, were found in 9 of 16 leads, mostly in frontal and central leads of both hemispheres and also in the left temporal leads.

DISCUSSION

In our study, we found noticeable delays in speech comprehension and production in children living in the residential care institution compared with family-reared children, which is in line with previous findings [2, 3]. At the same time, EEG recording demonstrated that listening for direct speech induced mostly desynchronization of the α -rhythm and synchronization of θ -, β -, and γ -oscillations in children of both groups. In these groups, reverse speech evoked desynchronization of all examined EEG rhythms in most leads. Such desynchronization can reflect an orientation reaction when the presented stimulus is speech-like but has no meaningful content.

There were several differences in EEG patterns observed in the examined groups during direct speech presentation. Family children demonstrated considerable decreases in the α -rhythm SPD in posteriorfrontal and temporal leads of the left hemisphere, as compared to those observed in situations of the eye-opened resting state and when listening to reverse speech. The orphans also demonstrated decreases in the SPD of the α -rhythm. This group of children demonstrated, however, significantly stronger desynchronization of the above rhythm in temporal leads of the right hemisphere and also in occipital areas of the cortex. As is known, the well-developed α -rhythm is typical of human EEG under conditions of relaxed wakefulness. Attention activation during perceiving of various supposedly important signals results in suppression of the α -rhythm [17-19]. Thus, desynchronization of the α -rhythm under conditions of direct speech perception was expectable. Moreover, the topographical pattern of the α -rhythm desynchronization during direct speech perception in the control group was in accordance with the known data that cortical regions responsible for meaning perception and generation of speech (Broca and Wernicke centers) are localized in the left hemisphere in most individuals. The right hemisphere is involved

in the analysis of paralinguistic information (speech intonation, rate, and volume) to a greater extent. Thus, it can be assumed that neuronal mechanisms of the right hemisphere are noticeably involved in the speech meaning perception in the institution-reared group. This is why it seems logical to suppose that neurophysiological mechanisms responsible for the ability to focus attention on the semantic content of the speech signal are developed insufficiently in such children.

As was mentioned earlier, significant synchronization of the θ -rhythm during direct speech presentation was observed in a majority of EEG leads (10 of 16) in family-raised children. In orphans, the same changes were detected only in two leads. The studies of some authors [17, 20, 21] demonstrated that intensification of θ -oscillations is a typical component of transformation of the EEG pattern upon activation of the cognitive and emotional processes. According to Klimesh et al. and Bastiansen and Hagword [18, 22], an increase in the θ -rhythm SPD occurs within the period of memorization of new and emotionally charged information. In this case, the memorization success positively correlates with the θ -rhythm power. These authors also supposed that increase in the θ -band power reflects activation of forward and backward connections between the hippocampus and neocortex during the process of formation of memory engrams. Considering this, we can conclude that the institution-raised children memorize verbal information less effectively.

Both examined groups demonstrated synchronization of β - and γ -oscillations during direct speech perception. In the institution group, however, synchronization of the above rhythms was weaker. It is still controversial what processes underlay synchronization of β -frequency oscillations. On the one hand, the presence of a clearly expressed β -rhythm in the EEG composition is interpreted as a reflection of the active state of both cortical and cortico-subcortical neuronal chains. Vrobel et al. [18] supposed that β -frequency oscillations in the cortico-thalamic chains reflect decreases in the threshold of activation of thalamic relay neurons. This provides a better selectivity of information flow to the corresponding neocortical areas in situations requiring attention. On the other hand, the power of the β -rhythm within the motor cortex decreases during movements (the so-called movement-related desynchronization), and it increases again after the movement has been completed [23, 24]. Intense

β -range oscillations with the amplitude up to 50 μ V were observed under conditions of pharmacotherapy with the use of benzodiazepines. Considering this, generation of the well-expressed β -rhythm is supposed to be related to the active state of, first of all, the inhibitory GABAergic neurotransmitter system in the corresponding cortical areas. This, in turn, should deprive other neuronal networks [25, 26].

When analyzing numerous contradictory facts, Angel and Fries [27] proposed a hypothesis on the functional importance of processes reflected in the generation of high-frequency (β - and γ -) EEG rhythms. During the performance of motor and cognitive tasks, the β -rhythm supports the ongoing motor state and helps during continuation and routine performance of the cognitive tasks. An inhibitory mechanism of the β -rhythm counteracts unexpected external influences and helps to preserve the *status quo* in the cortex. If an individual perceives an important external signal that requires additional mental efforts, not only the β -rhythm but also γ -oscillations are intensified. Other authors [16] noted, however, that oscillations corresponding to the β -frequency band are too slow for fast processing of information related to important events. Only synchronization of EEG oscillations within the γ -band frequency is able to rapidly link spatially distributed cell ensembles and thus to provide a necessary rate for cognition. Zeman [28] assumed that generation of the γ -rhythm is related to the activity of pacemaker neurons in the specific and intralaminar thalamic nuclei; in this situation, these cells generate spike bursts at about 40 sec^{-1} frequency. This phenomenon results in augmentation and synchronization of the activity of neurons concentrated in a few cortical regions, and this is the neurophysiological basis of effective integration of the coming information and awareness.

In our study, children were presented with novel audio information (an unknown poem). It is logical to assume that the child should exploit considerable additional resources of the brain to be able to attend to novel information. It is what we observed under direct speech conditions in this study, namely increases of the γ -rhythm in most leads of both hemispheres. Thus, semantically meaningful speech induces powerful synchronization of high-frequency oscillations within the EEG spectrum. We believe that a lower level of synchronization within the γ -range in the institutionalized children

reflects either delay or some deviations in the development of processing of speech meaning. This, in turn, reflects insufficient development of underlying cerebral neuronal networks responsible for processing of semantic verbal information. Thus, this situation can, at least partly, be improved via targeted correction during communication with “significant” adults when spending time with institutionalized children, and the age interval (2.5-3.5 years) considered in this study is, probably, especially important from this aspect.

The study described here was reviewed and approved by the Ethical Committee of the Vernadskii Tavricheskii National University and is in accordance with the ethical standards specified in the Declaration of Helsinki (1964). For the institution-reared group of children, official approval was obtained from the residential care management. The testing was performed in the presense of an institution psychologist. The family-reared group of children was recruited through announcements in the kindergartens of Simferopol’, and this group was matched to the institution-reared children in age and gender. Family-reared children were tested in the presence of a parent or a close adult relative. For family-reared children, informed consent was collected from parents prior to inclusion of their child in the study.

The authors of this paper, V. V. Belalov, Yu. O. Dyagileva, V. B. Pavlenko, and O. M. Kochukhova, confirm that they have no conflict of interest.

REFERENCES

1. P. Kuhl, “Brain mechanisms in early language acquisition,” *Neuron*, **67**, No. 5, 713-727 (2008).
2. F. Juffer, M.H. and Van Ijzendoorn, “Behavior problems and mental health referrals of international adoptees: A meta-analysis,” *J. Am. Med. Assoc.*, **293**, No. 20, 569-577 (2005).
3. C. H. Zeanach, A. T. Smyke, and S. F. M. Koga, et al., “Attachment in institutionalized and non-institutionalized Romanian children,” *Child. Dev.*, **76**, No. 19, 1015-1028 (2005).
4. S. R. Karel and B. J. Freeman, “Analysis of environmental deprivation: Cognitive and social development in Romanian orphans,” *J. Child Psychol. Psychiat.*, **35**, No. 4, 769-781 (1994).
5. M. Rutter, C. Colvert, J. Kreppner, et al., “Early adolescent outcomes for institutionally deprived and non-deprived adoptees. I: Disinhibited attachment,” *J. Child Psychol. Psychiat.*, **48**, No. 1, 17-30 (2007).
6. A. Tarullo, C. Garvin, and R. Gunnar, “Atypical EEG power correlates with indiscriminately friendly behavior in internationally adopted children,” *Dev. Psychol.*, **47**, No. 2, 417-431 (2011).
7. P. J. Marshall and N. A. Fox, “The Bucharest early intervention project core group. A comparison of the electroencephalogram between institutionalized and community children in Romania,” *J. Cogn. Neurosci.*, **16**, No. 8, 1327-1338 (2004).
8. S. Rossi, S. Telkemeyer, I. Wartenburger, et al., “Shedding light on words and sentences: near-infrared spectroscopy in language research,” *Brain Lang.*, **121**, No. 2, 152-163 (2012).
9. J. Silva-Pereyra, M. Rivera-Gaxiola, and P. K. Kuhl, “An event-related brain potential study of sentence comprehension in preschoolers: semantic and morphosyntactic processing,” *Cogn. Brain Res.*, **23**, No. 2, 247-285 (2005).
10. Z. Gou, N. Choudhury, and A. A. Benasich, “Resting frontal gamma power at 16, 24 and 36 months predicts individual differences in language and cognition at 4 and 5 years,” *Behav. Brain Res.*, **220**, No. 2, 263-270 (2011).
11. C. Krause, B. Porn, H. Lang, et al. “Relative alpha desynchronization and synchronization during speech perception,” *Cogn. Brain Res.*, **5**, No. 3, 295-299 (1997).
12. W. Jennekens, H. J. Niemarkt, M. Engels, et al., “Topography of maturational changes in EEG burst spectral power of the preterm infant with a follow up at 2 years of age,” *Clin. Neurophysiol.*, **123**, No. 11, 2130-2138 (2012).
13. T. A. Stroganova, E. V. Orekhova, and I. N. Posikera, “EEG alpha rhythm in infants,” *Clin. Neurophysiol.*, **110**, No. 6, 997-1012 (1999).
14. K. Cuevas, V. Raj, and M A. Bell, “A frequency band analysis of two year olds’ memory processes,” *Int. J. Psychophysiol.*, **83**, No. 3, 315-322 (2012).
15. N. Bayley, *Bayley Scales of Infant and Toddler Development*, TX Harcourt Assessment Inc., San Antonio (2006).
16. G. Pfurtscheller and F. H. Lopes da Silva, “Event-related EEG/MEG synchronization and desynchronization: basic principles,” *Clin. Neurophysiol.*, **110**, No. 11, 1842-1857 (1999).
17. W. Klimesch, “EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis,” *Brain Res. Rev.*, **29**, Nos. 2/3, 169-195 (1999).
18. A. Wróbel, “Beta activity: a carrier for visual attention,” *Acta Neurobiol. Exp.*, **60**, No. 2, 247-260 (2000).
19. M. Ploner, J. Gross, L. Timmermann, et al., “Oscillatory activity reflects the excitability of the human somatosensory system,” *Neuroimage*, **32**, No. 3, 1231-1236 (2006).
20. G. Buzsáki, “Theta oscillations in the hippocampus,” *Neuron*, **33**, No. 3, 325-340 (2002).
21. H. Laufs, J. L. Holt, R. Elfont, et al., “Where the BOLD signal goes when alpha EEG leaves,” *Neuroimage*, **31**, No. 4, 1408-1418 (2006).
22. M. Bastiaansen and P. Hagoort, “Event-induced theta responses as a window on the dynamics of memory,” *Cortex*, **39**, Nos. 4/5, 967-992 (2003).
23. N. E. Crone, D. L. Miglioretti, B. Gordon, et al., “Functional mapping of human sensorimotor cortex with electrocorticographic spectral analysis. I. Alpha and beta event-related desynchronization,” *Brain*, **12**, No. 12, 2271-2299 (1998).

24. C. Neuper and G. Pfurtscheller, "Event-related dynamics of cortical rhythms: frequency-specific features and functional correlates," *Int. J. Psychophysiol.*, **43**, No. 1, 41-58 (2001).
25. B. Porjesz, H. Begleiter, and K. Wang, "Linkage and linkage disequilibrium mapping of ERP and EEG phenotypes," *Biol. Psychol.*, **61**, Nos. 1/2, 229-248 (2002).
26. Yu. D. Kropotov, *Quantitative EEG, Event-Related Potentials and Neurotherapy*, Academic Press (2009).
27. A. K. Engel and P. Fries, "Beta-band oscillations – signalling the status quo?" *Curr. Opin. Neurobiol.*, **20**, No. 2, 156-165 (2010).
28. A. Zeman, "Consciousness", *Brain*, **124**, No. 7, 1263-1289 (2001).