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Cognitive Loading-Related Changes in the Coherence of EEG Rhythms in Hard-of-Hearing Adolescents

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We recorded EEG activity in 82 12- to 15-year-old adolescents suffering from sensorineural hearing loss (II or III degree) and 80 secondary-school similar-age pupils with normal hearing. Four pairs of recording electrodes (frontal, temporal, parietal, and occipital) were used. The recording was performed under resting conditions and during the performance of the Raven test, which provided the action of cognitive loading. In hard-of-hearing boys and girls in the resting state, the number of lead pairs with significant or high coherence of oscillations of the EEG rhythms (coherence coefficients, CC, 0.51 to 0.70 and 0.71 to 1.00, respectively) usually exceeded the respective figures in normally hearing adolescents. In boys of both groups performing the cognitive test, the number of lead pairs with the CCs exceeding 0.50 increased in most cases. This was especially significantly manifested with respect to theta activity in hard-of-hearing boys; a focus of intense coherence of theta oscillations was formed in subjects of this group in the right temporal area. In girls of both groups, cognitive loading usually did not induce considerable increases in the coherence of EEG rhythms; the number of lead pairs with CC values > > 0.50 either remained unchanged or even decreased. Thus, hard-of-hearing adolescents (especially boys subjected to cognitive loading) demonstrated an intense trend toward increase in coherence relations between remote cortical loci (generalization of coherence), i.e., toward the formation of more extensive associative networks. Changes in the spatial organization of coherent relationships under the action of cognitive loading demonstrate certain gender specificity.

Keywords: coherence, EEG rhythms, hearing loss, adolescents, cognitive loading.

INTRODUCTION

Children and adolescents suffering from hearing loss are characterized by certain peculiarities of mental and physical development and of the process of communication, which result from a primary insufficiency, a decrease in the intensity of the auditory afferent inflow [1, 2]. These features of hard-of-hearing subjects induce significant difficulties in their development, decrease their learning abilities, and interfere with gaining vitally necessary skills.

Hearing loss in early childhood significantly delays the adequate formation of speech and results in considerable difficulties for cognitive activity in general [1, 3]. Because of hearing loss, the volume of influences coming from the external environment in hard-of-hearing children is reduced, and interaction with the environment is somewhat depleted. This, in turn, together with the action of the above-mentioned factors, can lead to considerable changes in the functioning of a significant proportion of the brain systems, especially of the neocortical ones. Psycho-pedagogical research of hard-of-hearing children and adolescents exhibits, as a rule, a delay in the development of verbal/logical thinking, certain reduction of cognitive activity, an insufficient level of the formation of thinking processes, and disorders in the verbal component of the latter [1–6].

A considerable part of changes in the functional state of the brain can be detected by recording of EEG activity. Specific features of the recorded EEG patterns correlate with complex aspects of intracortical and cortico-subcortical interactions and neurodynamic processes realized in the respective cerebral structures. Multifacial modifications of the above patterns are related to certain changes in the normal functioning of the brain [5–7].

Examination of the characteristics of EEG activity of children and adolescents with hearing loss allows researchers to accumulate certain amount of information related to the above-described problem.

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At the same time, it should be recognized that information on the specificity of EEG activity in hard-of-hearing children and adolescents (i.e., in subjects that are in an ontogenesis period critically important for the development of the personality) remain insufficient. We studied this aspect of the functioning of the brain of hard-of-hearing adolescents by estimation of the spatial pattern of coherence relations between main EEG frequency components recorded from different cortical areas. Relatively high levels of coherence of certain EEG rhythms observed in different cortical loci are interpreted by many researchers as indications of functional association of the respective spatially separated neuronal systems in integrated complex neuronal networks.

METHODS

The examined group included 82 12- to 15-year-old adolescents with hearing disabilities; the group was formed on the basis of the Kherson boarding school No. 29 for children with hearing disorders. In members of this group (40 boys and 42 girls), sensorineural hearing loss of degrees II or III was diagnosed. The control group included 80 pupils of the Kherson secondary school No. 30; these were adolescents of a similar age with normal hearing. All examined children, according to their self-assessment and results of manual tests (interlacing of the fingers, crossing arms on the chest, dynamometry, applause, and abilities to write using the right and left hands) were dextrals.

EEG recording was carried out using a computerized electroencephalographic set, "Braintest" (Kharkiv, Ukraine). Recording electrodes were placed according to the international 10–20 system in eight symmetric projections, right (d) and left (s) frontal (Fs, Fd), occipital (Os, Od), parietal (Ps, Pd), and temporal (Ts, Td). Coupled contacts on the earlobes were used as the reference electrode. Electrodes were fixed using a rubber EEG helmet. EEG recording was performed in a light- and sound-proof chamber. The amplifier bandwidth was 1.00–30 Hz, and the digitization frequency was 50 sec^{-1}. We analyzed 60-sec segments of the records, and the analyzed epochs were 2000 msec long. The following EEG frequency bands (rhythms) were taken into account: delta (0.2–3.8 Hz), theta (4.0–7.8 Hz), alpha (8.0–12.8 Hz), and beta (13.0–30 Hz). Fragments of EEG records coinciding with blinking of the eyes or with other forms of motor activity were excluded from the analysis.

The levels of coherence of main EEG rhythms were measured under functional resting conditions and upon the action of the cognitive loading associated with the Raven test (see below). The coherence of EEG oscillations, i.e., the level of their frequency/phasic coincidence (regardless of the power of these oscillations), was characterized by calculation of the coefficient of coherence (CC). Calculations of the CCs were performed using the electroencephalograph software. The CC values smaller than 0.30 were interpreted as signs of weak coherence of the respective EEG oscillations, CCs between 0.31 and 0.50 corresponded to moderate coherence, those between 0.51 to 0.70 corresponded to significant one, and CCs of 0.71–1.00 were indicative of the high coherence. In our study, we took into account only significant and high CC values (i.e., those exceeding 0.50). We also calculated the normalized number (share) of cases with such CCs, taking the number of all possible pairs of EEG leads (in our case, 28) as 100%.

Cognitive loading on the examined subjects was provided using the Raven test. The latter is a nonverbal test that requires the involvement of visual creative (figurative) thinking. The test is directed toward establishing logic regularities in the formation of an orderly series of graphic objects (composite geometric forms having a limited number of features). The test consists of several versions with different levels of complexity; we used a version corresponding to the age of adolescents involved in the experiments (12–15 years).

RESULTS

In normally hearing boys and girls in the resting state, strong interhemisphere coherence of low-frequency EEG components (delta rhythm) was typical of the frontal lead pair. A focus of coherence was also manifested in the parietal/occipital cortical region; it was based on a combination of interhemisphere and intrahemisphere coherence relations. Under conditions of cognitive test loading, the total number of coherent relations of delta activity in the cortex of normally hearing boys demonstrated no changes. In the course of the test performance by girls, this index increased ($P < 0.05$) due to the arrival of additional significant intrahemisphere relations in both hemispheres (Fig. 1, A).