Neurophysiology, Vol. 50, No. 5, October, 2018

Coherent Relations in EEGs of Adolescents with Partial Hearing Loss under Conditions of an Orthostatic Test

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Received January 10, 2018

Results of the examination of transformations of coherent relations in EEGs under conditions of realization of an orthostatic test (OT) by adolescents with normal hearing and partial hearing loss (NH and PHL groups) are described. The OT performance was mostly characterized by spatial redistribution of the lead pairs with significant values of the coefficient of correlation (CC) and not by changes in the number of such lead pairs. The formation of an activity focus within posterior areas of the cortex after the OT was a general regularity in both examined groups and in all frequency ranges, independently of the existence of such a focus in the given examined group under conditions of functional rest. It was found that EEGs of adolescents with partial hearing loss were characterized by a smaller in the number of the lead pairs with significant CCs for the α rhythm due to disappearance of anterior coherent zones in both hemispheres of PHL girls; in PHL boys, this was observed only in the left hemisphere. We believe that the specificities of coherent relations in PHL adolescents under conditions of the OT may be determined by a greater tension in the adaptation systems and an insufficiency of the neocortical inhibitory systems; these deficiencies develop because of limitation of the sensory inflow to cortical neurons and, correspondingly, of a decrease in the tone of the respective neuronal networks.

Keywords: EEG, coherence, adolescents with partial hearing loss, adolescents with normal hearing, EEG rhythms, orthostatic test.

INTRODUCTION

Examination of physiological and psychological characteristics of adolescents suffering from sensoneural hearing loss showed that this contingent demonstrates certain peculiarities of the above characteristics determined by the sensory deficiency. Among these peculiarities, there were an insufficiency of inhibitory influences coming from the cortex in the cerebral synchronizing structures, intensified activity of the latter structures, functional insufficiency of the thalamo-cortical system, a noticeable retardation in the development of verbal/logical thinking, decreased cognitive activity, insufficient formation of the thinking processes, disorders in verbal thinking, etc. [1–4]. Because of an insufficient sensory inflow, adolescents with PHL frequently show significant delays in the formation of speech and in cognitive activity in general [3, 5]. At present, further studies of specificities of the functional organization of the brain in subjects with certain sensory defects are rather urgent. These specificities can be more successfully detected under conditions of some functional loadings.

The orthostatic test (OT) is extensively used in clinical practice, especially in examinations of the excitability of the medullary vasomotor center [6, 7]. In our earlier studies, we found that adolescents with PHL are characterized by relative functional insufficiency of the activatory midbrain reticular formation. Taking into account that the vasomotor center (a crucial neuronal center activated during the OT) is in fact a part of the brainstem reticular formation, it was possible to suppose that peculiarities of the functional EEG changes in adolescents suffering from PHL could be more clearly detected under conditions of the OT performance (i.e., under conditions of loading on the above brainstem formation). This should be expected despite the fact that there are no direct relations between the above center and the auditory system.

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METHODS

Two groups of adolescents were involved in the test. The first group was formed from 12- to 15-year-old teenagers suffering from hearing loss, pupils of the Kherson boarding school No. 29 for children with hearing deficiencies. This group included 82 adolescents with sensoneural hearing loss of the second or third degree (40 boys and 42 girls). The second (control) group included 80 pupils of the Kherson general secondary school No. 30 (40 boys and 40 girls). All examined adolescents were dextrals according to their self-estimation and results of the manual tests (interweaving of the fingers, crossing of the hands on the breast, dynamometry, applauding, and abilities to write with the right and left hand).

Recording of EEGs was performed using a computerized EEG system, “Braintest” (DX-Systems, Ukraine). Recording electrodes were positioned according to a generally used international system, 10–20, in eight symmetrical projections (frontal, Fs and Fd, occipital, Os and Od, parietal, Ps and Pd, and temporal, Ps and Pd). Interconnected electrodes on the earlobes were used as a reference electrode. Electrodes were fixed on the scalp using a rubber helmet. During EEG recording, the subjects were in a light- and sound-proof chamber. The frequency band for the amplification and recording tracts corresponded to 1.0 to 30.0 Hz; the digitization frequency was 50 sec^{-1}. Sixty-sec-long EEG segments were analyzed; the epoch of analysis was 2000 msec long. The following frequency ranges (EEG rhythms) were differentiated: δ (0.2 to 3.8 Hz), θ (4.0 to 7.8 Hz), α (8.0 to 12.8 Hz), and β (13.0 to 30.0 Hz).

Before EEG recording, all examined subjects were informed in detail on the safety and painlessness of the procedure, its stages, and approximate duration.

We used coherent analysis of the background EEGs and EEG segments recorded during and after the OT. As is known, calculations of the coherence coefficients (CCs) are used for estimation of the level of interrelations between EEG rhythms in different brain sites independently of the power of EEG oscillations in these sites. The CCs are normalized values; their levels may vary between 0 to 1.0. In the case of CCs below 0.30, we classified the level of coherence as a low one. At CCs of 0.31 to 0.50, this level was considered medium, at 0.51 to 0.70, it was considered significant, while CCs above 0.71 were indicative of a high coherence level. In our study, we took into account only significant and high values of the CCs. Proportions of the significant and high coherence relations with respect to all possible ones were also estimated.

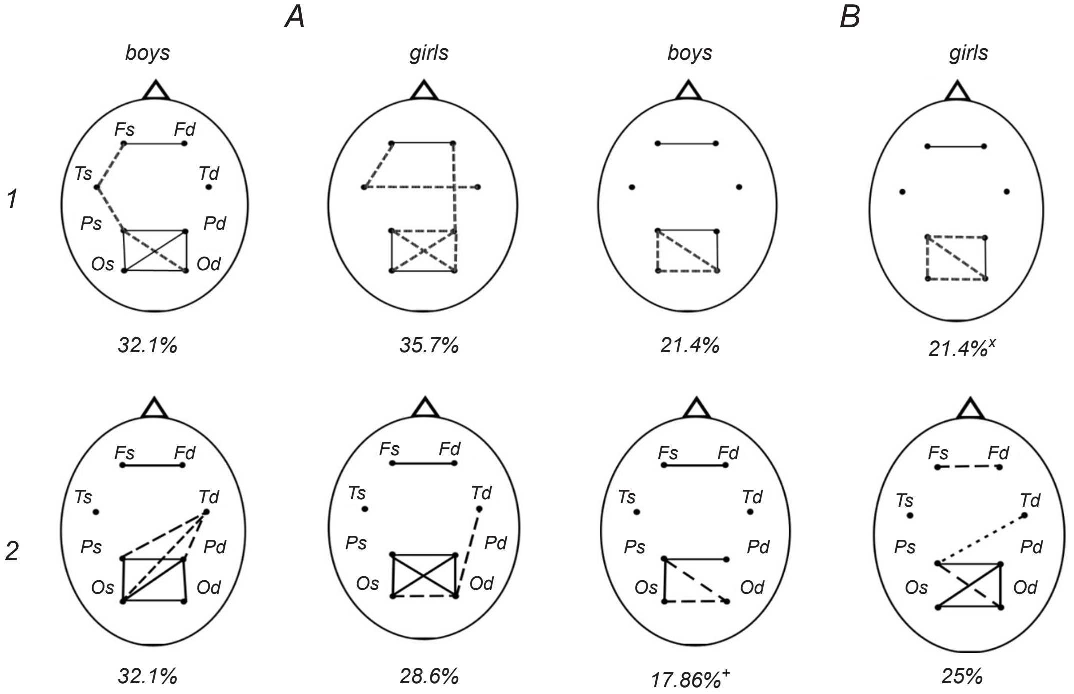
RESULTS AND DISCUSSION

In the resting state, NH boys and girls were characterized by high interhemisphere coherence of δ oscillations in the frontal lead pair and by the presence of a focal region of coherence in the parieto-occipital cortical zones (with a combination of inter- and intra-hemisphere relations.

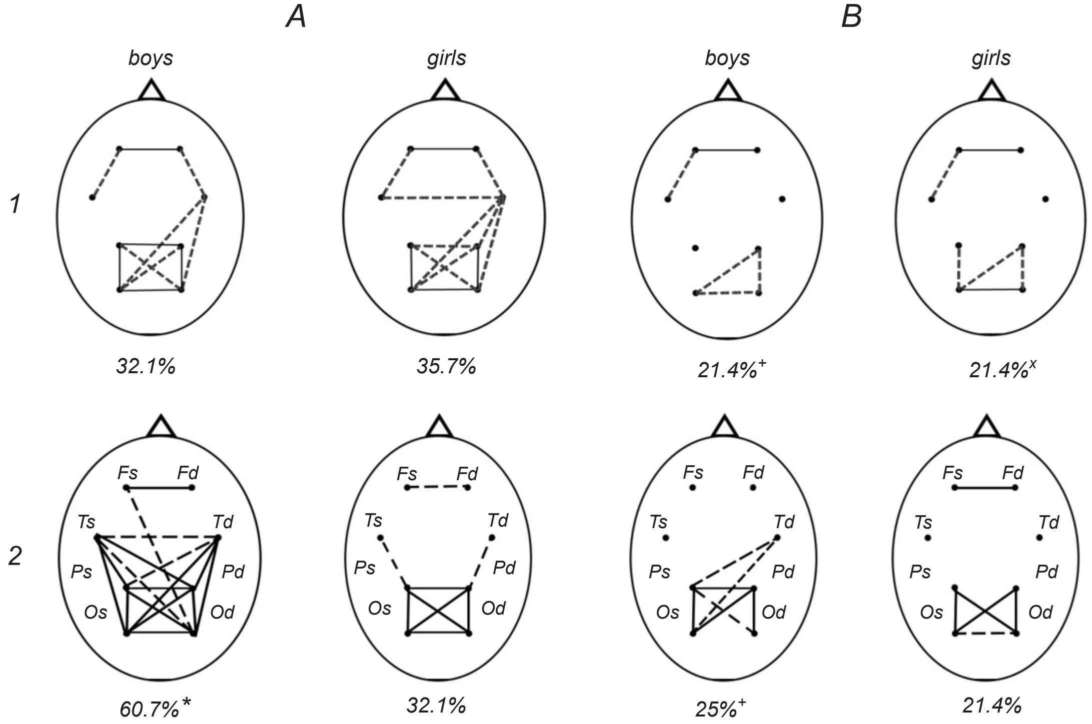
In the course of realization of the OT by NH boys, an insignificant decrease in the total number of lead pairs with a considerable level of the CCs for δ activity was observed. This occurred due to a weaker of coherence in the intrahemisphere parieto-occipital pair in the left hemisphere. Realization of the OT by NH girls resulted, *vice versa*, in an increase of the number of EEG lead pairs with significant levels of coherence of δ activity due to the arrival of coherent pairs in the left parietal and right temporal zones and also in the left occipital and right parietal cortical zones.

Boys and girls suffering from PHL and examined under conditions of functional rest differed from NH adolescents by a greater number of lead pairs with high CC values (> 0.50) for δ oscillations. Similarly to what was observed in NH adolescents of the same age, teenagers with hearing deficiencies were characterized by a focal region with coherent δ oscillations in the frontal areas and parieto-occipital regions of the cortex, but intrahemisphere coherence relations were added to this pattern. In girls with PHL, the difference between lead pairs with high CCs in the resting state reached the significance level, as compared with that in NH girls.

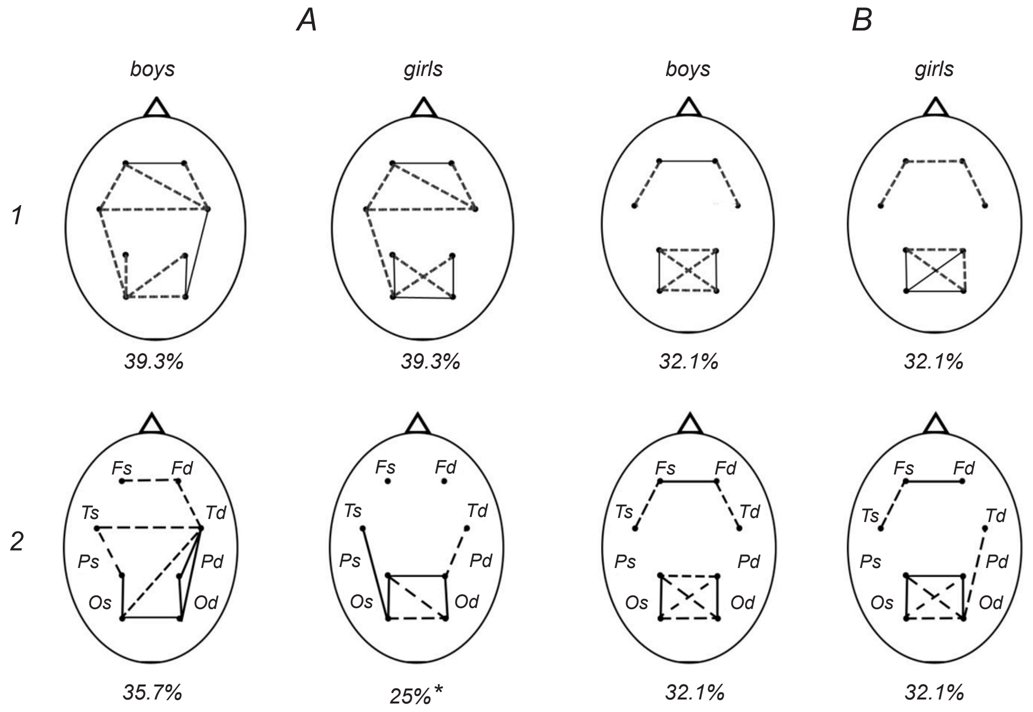
The performance of the OT by boys of the PHL group did not change the total number of lead pairs with significant coherence levels for the δ range. At the same time, the spatial rearrangement of such pairs was observed. The number of “longitudinal” intrahemisphere lead pairs with significant levels of the CCs for δ activity in the left hemisphere decreased, but a focus of coherent EEG activity in the right temporo-parietal region was formed. In this case, the number of pairs of EEG leads with significant levels of coherence of δ oscillations in boys with PHL during the OT was significantly greater than the respective indices in NH boys.



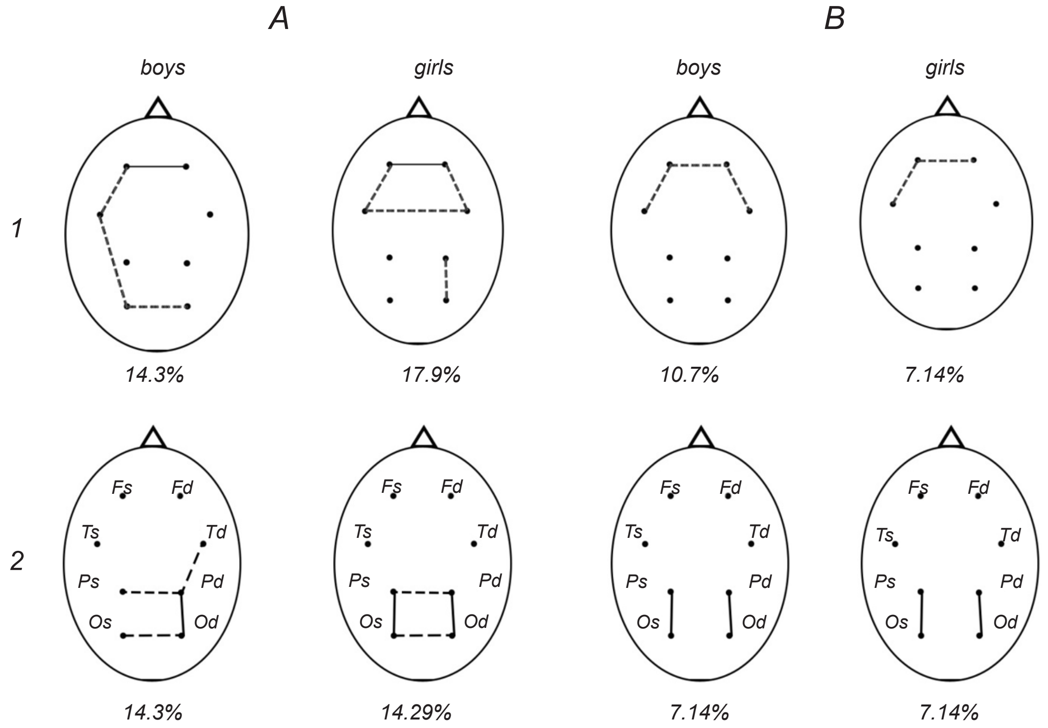
F i g. 1. Spatial organization of coherent relations between δ oscillations in adolescents with partial hearing loss (A) and normal hearing (B) in the state of functional rest (1) and in the course of orthostatic test (2). Dashed and solid lines indicate coherent relations between the recording loci (frontal, Fr, temporal, T, parietal, P, and occipital, O) with significant and high levels of coherence (coefficients of coherence, CCs, 0.51–0.70 and 0.71–1.0, respectively). Proportions, %, of relations with significant coherence levels (CC > 0.50) with respect to the number of all possible combinations of relations ($N = 28$, taken as 100%) are shown below the schemes. Asterisks show cases of significant differences in comparisons of the indices observed during the OT with those in the state of functional rest within the borders of a single examined group. Crosses and diagonal crosses show analogous cases in comparisons of the indices in boys and girls of different groups; respectively.



F i g. 2. Spatial organization of coherent relations between θ oscillations in adolescents with partial hearing loss (A) and normal hearing (B) in the state of functional rest (1) and in the course of orthostatic test (2). Designations are similar to those in Fig. 1.



F i g. 3. Spatial organization of coherent relations between α oscillations in adolescents with partial hearing loss (A) and normal hearing (B) in the state of functional rest (1) and in the course of orthostatic test (2). Designations are similar to those in Fig. 1.



F i g. 4. Spatial organization of coherent relations between β oscillations in adolescents with partial hearing loss (A) and normal hearing (B) in the state of functional rest (1) and in the course of orthostatic test (2). Designations are similar to those in Fig. 1.

In the group of girls with PHL, the OT induced a decrease in the total number of lead pairs with significant levels of coherence of δ-range oscillations due to the disappearance of the "coherent" area in the fronto-temporal cortical region.

In NH boys and girls in the state of functional rest, the number of lead pairs with significant coherence of θ oscillations (CC > 0.50) was rather limited. Realization of the OT induced an increase in the number of pairs with significant θ coherence in NH boys. In this case, a focus of activity was formed in the right temporal locus of the brain cortex. In NH girls, the total number of lead pairs with significant coherence of oscillations of the θ range after the OT showed no changes; at the same time, certain rearrangement of this part of EEG activity was observed. The number of the above-mentioned "θ" pairs in the anterior loci decreased, while coherence in the parieto-occipital cortical loci was intensified.

In the state of functional rest, boys and girls of the PHL group showed a considerably greater ($P \leq 0.05$) number of lead pairs with significant coherence of θ-range oscillations. The spatial distribution of such relations was characterized by the presence of a parietal focus of coherent θ activity.

After the OT performed by boys and girls with PHL, spatial distribution of coherent relations in the θ range was subjected to considerable modifications. In boys, a transition to the upright position induced a significant increase in the number of EEG lead pairs with relatively high levels of θ coherence; at the same time, not only the number of such pairs, but also the pattern of their distribution underwent changes. The lead pairs with a significant level of coherence of the above oscillations were localized, similarly to what was observed in the resting state, mostly within parieto-occipital cortical zones, and their spatial distribution after the OT acquired a symmetric character.

The OT performance by girls with PHL led, unlike to what was observed in boys with PHL, to a decrease in the number of lead pairs with significant coherence of θ range oscillations. In this case, the spatial distributions of such leads also became symmetrical.

In NH boys and girls in the resting state, the number of EEG leads with a significant coherence level of α oscillations was moderate in both examined subgroups (32.1% from all possible relations). The spatial distribution of such lead pairs was nearly similar; there were two foci of coherent α activity, in the fronto-temporal and parieto-occipital parts of the cortex.

Realization of the OT induced nearly no changes in the number and spatial distribution of lead pairs where a significant level of coherence of α oscillations was observed in NH adolescents. Only in EEG of NH girls did the level of coherence in the right fronto-temporal lead pair drop below the significance level. At the same time, the level of coherence of α activity in the right temporo-occipital pair increased.

Boys and girls of the PHL group were characterized by the existence of two "coherent" zones for α activity; these zones were localized in the parieto-occipital and fronto-temporal cortical zones. In the resting state the general number of pairs with significant CCs for the α range in boys and girls suffering from PHL was greater than the respective indices of NH boys and girls.

Realization of the OT by boys with PHL led to a decrease in the number of lead pairs having significant CCs for the α range; this difference, however, did not reach the significance level. Simultaneously, some spatial redistribution of the lead pairs with significant "α" CCs occurred; a clear focus of such relations was formed in the right temporal zone. Coherent relations of α oscillations with five zones of the cerebral cortex, right frontal, left temporal, both occipital, and right parietal ones, converged to this focus.

Girls with PHL demonstrated a significant decrease ($P < 0.05$) in the number of pairs with a high level of CCs for the α range after realization of the OT. In this case, the "coherent region" in the fronto-temporal zone of the cortex disappeared; at the same time, such region in the parieto-occipital zone of the neocortex was preserved.

In the resting state, NH boys and girls were characterized by a rather limited number of the EEG lead pairs with a significant level of coherence of β oscillations. Such pairs in both examined groups were localized within the anterior half of the neocortex.

Realization of the OT by NH boys led not only to a decrease in the number of lead pairs with significant CCs for β activity but also to redistribution of EEG β activity; the latter phenomenon was also observed in NH girls. The level of coherence of β activity in lead pairs within anterior cortical regions decreased below the significance level, while such levels in "longitudinal" intrahemisphere parieto-occipital pairs of both hemispheres began to be significant.

In boys and girls with PHL, the number of lead pairs with significant coherence of β activity observed in the resting state was rather limited but greater than that in NH boys and girls. The performance of the OT by PHL boys did not affect the number of lead pairs with significant coherence of β oscillations but modified spatial distribution of such pairs. In the state of functional rest, such relations were observed in "longitudinal" left intrahemisphere pairs and also in symmetric frontal and occipital pairs. After the OT, the coherence of β activity exceeded the significance level in symmetric parietal and "longitudinal" intrahemisphere temporo-parietal and occipito-parietal pairs at the right side.

Realization of the OT by girls with PHL resulted in a mild decrease in the number of EEG lead pairs with significant CCs for β activity. The spatial distributions of such pairs demonstrated changes similar to those in NH adolescents. In the resting state, coherent lead pairs for the β range were distributed in PHL girls within anterior parts of the neocortex. After realization of the OT, β activity began to demonstrate significant coherence levels within posterior parts of the neocortex, and a parieto-occipital "coherence area" was formed.

Thus, we found that the OT performance was mostly characterized not by dramatic changes in the number of EEG lead pairs with significant CCs, but by spatial redistribution of such pairs. The formation of an activity focus in the posterior regions of the neocortex after realization of the OT was a common phenomenon observed in both examined groups and all EEG frequency ranges; this was independent of the presence/absence of this focus in the given examined group in the state of functional rest.

For the δ range, both examined groups demonstrated the formation of the focus of coherent activity in the occipito-parietal zone of the cortex and in the right temporal area (boys with PHL were an exception with respect to the latter fact). Both girls with PHL and NH boys were characterized by decreases in the number of EEG lead pairs with significant δ coherence; in NH girls, the number of such pairs, however, increased.

For the θ range, the number of EEG lead pairs with significant CCs increased after the OT in both examined groups of boys. For this frequency range, the formation of the temporo-parieto-occipital coherence zone was typical; in boys with PHL this zone was symmetrical, while in NH boys this was observed only at the right side. Girls with PHL were characterized by an OT-related decrease in the number of coherent pairs for θ activity; the distribution was symmetrical and corresponded to the temporo-parieto-occipital area. Normally-hearing girls did not show changes in the number of coherent pairs, but the formation of the posterior coherent zone was also manifested in this group.

The distribution of coherent lead pairs for the α range in NH adolescents was not subjected to significant modifications after the OT. Realization of the test by boys with PHL was accompanied by a decrease in the number of lead pairs with significant "α" CCs due to disappearance of the anterior coherent zone in both hemispheres in girls with PHL and in only the left hemisphere in boys with such hearing defect.

All examined groups demonstrated certain spatial redistribution of coherent lead pairs for the β range induced by the OT, as compared with the state of functional rest. This was a shift of the coherent zone from the anterior cortical parts toward posterior ones.

The transition of tested subjects from the horizontal to the vertical body position is accompanied by redistribution of blood within the body. Due to the action of hydrostatic forces on the blood vessels, the blood is held up in the lower parts of the body, the blood inflow toward the heart decreases, the systolic blood volume also decreases, and the heart rate, correspondingly increases [6, 7, 9]. Regulation of the activity of the cardio-vascular system is realized at the level of the vasomotor center of the medulla; the activity of this center is subjected to descending control from upper cerebral centers.

The appearance of the posterior coherent zone in both examined groups and practically in all examined EEG frequency ranges is related to activation of the brainstem reticular formation in the course of transition of the body from the horizontal to the vertical position. A certain decrease in the number of coherent lead pairs for relatively high-frequency rhythms (α and β) in EEGs of adolescents with PHL may be related to the involvement of a greater number of brainstem neurons in the course of adaptation of the circulation to new functional conditions and, correspondingly, to stronger excitation of the brainstem synchronizing neuronal structures. In a resting state, PHL adolescents are probably characterized, on average, by a greater activity of the brainstem structures and a lower activity of neocortical neurons compared to those in NH subjects [5]. The adoption of a vertical position (upright stance) leads to some transient weakening of the blood supply of the upper half of the body (including the head) and, accordingly, to the brain [7–10]. This can lead to an additional decrease in the activity of the cerebral cortex and relative increase in the effects of activity of the brainstem synchronizing structures. In the group of NH adolescents, we did not observe significant changes in the number of coherent pairs for the high-frequency rhythms. This may be related to the higher perfectness of the system of adaptation mechanisms and inhibitory systems in the neocortex.

According to the results of a few studies, individuals with PHL frequently suffer from disorders of the vestibular system and intense vertigo [1, 2, 4]; these phenomena are clearly manifested in the course of OT. The influence of gravitation-related effects on the activity of the cardiovascular system during the orthostatic test is relatively more intense in subjects having a reduced adaptional ability of the regulatory systems of blood circulation. We believe that the peculiarities of coherent relations in the cortex manifested in the course and after the OT in adolescents with PHL can be related to a greater tension in the adaptation autonomic systems and some insufficiency of the neocortical inhibitory systems [1, 4, 5]. These peculiarities can result from limitation of the auditory sensory inflow to cortical neurons and, respectively, from a lower tone of the respective cortical networks in such individuals. The orthostatic test is a simple and easily reproducible method in functional studies of the regulatory systems in humans. Examination of changes in the coherence of EEG activities in PHL adolescents showed that cerebral adaptational systems probably work in these subjects with some tension.

The study was carried out in strict accordance with the statements of the Helsinki Declaration (1975, revised and supplemented in 2000) and directives of the National Committee on Ethics of Scientific Research. All involved subjects gave their written informed consent.

The author, A. V. Shkuropat, declares the absence of any conflict in commercial or financial relations, relationships with organizations or persons that in any way could be related to the study.

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