EEG Markers of Upright Posture in Healthy Individuals

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Abstract—The EEG spectral—coherence parameters were analyzed in 10 healthy individuals (mean age, 22 ± 0.67 years) at different steps of verticalization, from the lying position to the sitting and standing positions. The maximal changes in all EEG parameters were revealed when the upright posture was maintained in the absence of visual control. Under these conditions, a power increase for the fast EEG components (the β- and γ-bands) was observed, as was an additional increase when the conditions of maintaining the upright posture were complicated. According to the results of the EEG’s coherent analysis, human verticalization revealed a specific increase for most of the EEG rhythm ranges in the right hemisphere, especially in the frontocentral and occipitoparietal regions, as well as for the interhemispheric coherences for these leads reflecting the involvement of both cortical and subcortical structures in these processes. When the posture maintenance conditions were complicated, an additional coherence increase in the fast EEG bands (the β-rhythm) was observed in the frontal cortical regions, which was evidence of the increase in the executive functions under these conditions.

Keywords: vertical posture, EEG, power, coherence

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The voluntary control of the upright posture exercised by humans during their lifetime is an important physiological function of the body. The maintenance of the upright posture of the body by humans involves both the motor and sensory systems, which differs qualitatively from that of other vertebrates and requires fine regulation. A large number of investigations deal with the features of exercising control over the upright human posture based on studying the laws of the biomechanics of posture regulation [1–4].

The control of the upright posture is determined by the aggregate correcting activity of the trunk and lower limb muscles, as well as by multifarious synthesis with the predominance of proprioceptive and tactile information at every moment of time [5–10]. The problems of the biomechanical regulation of posture, the character of effector influences, and the necessary sensory information in the course of maintaining an upright posture have been studied in greater detail than the central mechanisms of its organization [3, 6, 10–12].

The concept of multilevel construction of voluntary movements suggested by N.A. Bernstein assumes a hierarchy of interactions between the brain’s centers in the course of regulating motor activity, which holds for the function of control of the upright posture [1–3, 12]. However, the neurophysiological mechanisms and the dynamics of interaction between the brain’s structures when a human passes from the horizontal to the upright position are not clearly understood.

However, understanding these mechanisms is of both theoretical and practical interest, as it is known that there are situations in clinical practice when voluntary postural control is disturbed by a severe traumatic brain injury (TBI), acute cerebral circulatory disorders, Parkinson’s disease, etc. TBI is of special interest, because individuals with a traumatic brain injury are mainly young, premorbidly intact, and able-bodied [13, 14]. The recovery of these patients with the subsequent readaptation to work seems to be an important medical task, and the restoration of voluntary control of the upright posture of the body is one of the main stages of their rehabilitation [14–17]. The fundamental knowledge of the neurophysiology of regulating the upright position of the body of a healthy human is necessary for the search for more efficacious rehabilitation approaches, as is the knowledge of the mechanisms of the impairment and recovery of this function in patients who suffered TBI.

The mathematical analysis of the EEG, in particular, of coherence reflecting the degree of functional linkage (combined state) between the cortical regions of the brain is a informative method for studying the neurophysiological mechanisms of human cerebral activity. This approach was widely used in numerous investigations aimed at studying human motor, cognitive, and emotional activity in brain health and pathology and may be promising for studying the neurophysiological mechanisms of postural control [18–29].

The data generally pertaining to this problem available to date, which have been obtained with the use of the conventional EEG, clarify the involvement of different brain structures in correcting the body position in instability or during the preparation for a purposeful
movement [30–33]. At the same time, the problem of the mechanisms of different stages of human verticalization (from the lying to the sitting and standing positions) still needs to be understood in greater detail, because standing underlies the performance of all voluntary movements. Modern technologies, in particular, telemetric EEG, have proved to be promising for studying the behavior of the functioning and the character of interaction between the brain’s structures under different motor loads, which is technically difficult with the use of the conventional EEG [34].

The aim of this investigation was to study the specific features of modulation of the spatiotemporal EEG organization in healthy individuals when they transfer from the lying to the sitting and standing position in the presence and absence of visual control.

METHODS

Ten healthy subjects (four men and six women with an average age of 22.8 ± 0.67 years) were enrolled in the study. Telemetric EEG was recorded in the lying, sitting, and standing position on the floor and on a force plate (under all the conditions with the eyes open and closed) for 60–70 s for each experimental situation. A change in the body position was followed by intervals of 3 to 5 min in duration with the subsequent EEG recording.

Telemetric EEG recording was carried out using an Entefalan hardware-and-software complex (Taganrog, Russia) with 18 electrodes arranged according to the international 10–20 scheme. After removing the artifacts, the EEG fragments were processed using the original software that enabled the significance of differences between multiple power and coherence parameters to be determined with the method of pairwise comparisons described in detail earlier [23, 24, 34]. The power and coherence spectra were calculated for 5-s epochs (a total of no less than 10 epochs were taken) for six EEG rhythm ranges ($\Delta$, 2–3.9 Hz; $\theta$, 4.3–7.8 Hz; $\alpha_1$, 8.2–10.1 Hz; $\alpha_2$, 10.5–12.1 Hz; $\beta$, 12.3–30.1 Hz; and $\gamma$, 30.1–40.2 Hz).

RESULTS

Analysis of the EEG power spectra with the eyes open when passing from the lying to the sitting position (Fig. 1) revealed a greater power increase in the fast EEG rhythms—the diffuse $\gamma$- and $\beta$-ranges—in the frontal leads, which was associated with the power decrease in the other EEG rhythms including the $\alpha$-bands. With transition to the upright posture (standing on the floor), an additional power increase was observed only in the $\gamma$-range, predominantly in the central and parietal divisions. Upon stepping onto the force plate, which requires greater efforts for keeping balance (compared to standing on the floor), an additional power increase was observed in the $\gamma$-range, more in the left frontal, central, and parietal regions.

With the eyes closed, the pattern of the EEG power dynamics revealed the following changes in similar experimental situations (Fig. 2): with transition to the sitting position, a power increase was also observed in the fast $\beta$- and $\gamma$-bands, predominantly in the parietal and occipital areas, in combination with a diffuse decrease in the other EEG components—the $\alpha$, $\theta$, and $\Delta$-ranges. Upon the transition to the upright posture, the maximal power increase in the $\beta$-range, as well as in the $\alpha_2$- and $\gamma$-ranges, was observed. The complication of the upright posture was accompanied by the predominant power decrease for the $\gamma$-range.

The changes in the EEG coherence with the eyes open (Fig. 3) with transition from the lying to the sitting position consisted in the increase of coherence in the occipital divisions for the $\Delta$- and $\alpha$-range, combined with the decrease of coherence in the $\theta$- and $\alpha$-rhythm range, more in the central and frontal regions. Transition to the standing position was accompanied by an increase in coherence of the EEG in the $\beta$-range, predominantly in the central regions, in combination with its decrease for the $\Delta$, $\theta$, and $\alpha_1$ bands in different regions of the cortex. The complication of the upright posture was accompanied by a marked EEG coherence increase in the $\alpha_1$-, $\theta$-, and $\beta$-bands, especially in the frontal and central regions. The predominant coherence increase in the right hemisphere, especially in the occipito-parietal areas, for all the ranges of the rhythms, except for the $\beta$- and $\gamma$-range, merits attention.

With the eyes closed (Fig. 4), the transition from the lying to the sitting position was accompanied by a diffuse coherence decrease for most rhythm ranges, except the $\Delta$-range, in the occipito-parietal areas. Upon transition to the standing position, a marked coherence increase was observed for practically all the rhythm ranges (except the $\gamma$). The predominant EEG coherence increase in the right hemisphere, especially in its central and occipitoparietal regions, for all the bands merits attention. Note that a marked coherence increase was also observed for the $\theta$- and $\alpha_1$ range in the fronto-central regions. The complication of the maintenance of the upright posture was accompanied by an additional EEG coherence increase in the right occipitoparietal regions for all the ranges (except for the fast rhythms), as well as in fronto-central areas for the $\Delta$- and $\theta$-band.

DISCUSSION

The features of changes in the EEG spatiotemporal organization were revealed during verticalization of healthy individuals, i.e., transition from the lying to the sitting and standing position. The analysis of the spectra of EEG power demonstrated its predominant increase for the high-frequency rhythm ranges, $\alpha_2$, $\beta$, and $\gamma$, in the absence of distinct regional specificity. The maximal EEG power changes were observed in the absence of visual control, as well as when the postural instability of the subject increased. This agrees