Effects of electrical polarization in neurophysiology of heart and brain

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Abstract

To substantiate the influence of electrophysics of the heart on the cognitive functions of the brain, we studied the interdependence of frequency spectra of EEG and ECG in various states of visual and auditory systems of brain. A correlation was found between changes in the activity of visual zones of cerebral cortex and ECG frequency caused by voice acoustics, the introduction of alcohol into the blood, and an increase in blood pressure. Bone conduction enhances effects of voice acoustics on electrophysiology of left hemisphere of brain in a right-handed person when the ears are occluded with fingers, due to an increase in quality factor of resonant cavity of outer ear. To explain the relationship between electrophysiology of brain and heart, it was suggested that pulse oscillations of arterial blood in arterioles and capillaries of brain parenchyma are modulated by oscillations of electrical polarization of water base of blood caused by rhythmic activity of correlated ensembles of conducting and contractile cardiomyocytes of left ventricular myocardium.

Key words: electroencephalography, cardiomyocytes, neuroglia, polarization, blood, water.

1. Introduction

Living organisms and their individual organs are generally electrically neutral. However, at the micro level, the energy of electrical interactions of ion charges, dipoles of molecules, polarized surfaces and media is responsible for the movement and functioning of plant and animal organs [1-5]. The main sources of energy for the generation of free charges and polarization of media are exothermic reactions of glucose oxidation and electrolyte hydration [6-9]. In these reactions, a redistribution of electron and proton density occurs between the reactants, oxygen and water. In the mechanisms of charge separation in receptors of external signals, energy of signals themselves plays an important role [2]. For example, the action of light on the retina leads to the appearance of a dipole directed along the axis of the eyeball [3, 7]. Its field can introduce significant distortions in the distribution of potentials in the frontotemporal leads of the electroencephalogram (EEG) [3]. Mechanical vibrations of the basilar membrane of the cochlea with the participation of the potentials of endolymph and perilymph are converted in receptor cells into action potentials (AP) of the auditory nerve [2, 10]. External thermal energy, due to the mechanism of thermoreception and vision synesthesia, activates the electrophysiology of pressure phosphenes [7].

The most powerful generator and consumer of electrical energy in a living organism is its heart. The equivalent of this energy is kinetic energy of arterial blood, and dynamics of integral current dipole of heart is manifested by potentials of electrocardiogram (ECG) throughout the human body [11, 12]. These potentials, as well as the EEG potentials, reflect the effects of polarization of body and brain tissues caused by current dipoles in synapses of neurons in the case of brain [11] and the sum of elementary current dipoles of conducting and contractile cardiomyocytes [12]. The magnitudes of polarization effects in biological tissues depend on content of water in them, which limits orientational mobility of tissue molecules, and itself has a large dipole (~2.8 D), especially in clusters [8, 9, 13].

Blood is ~90% water and includes about 2-3% inorganic ions (Na^+, K^+, Ca^{2+}, HCO_3^-, Cl^-, etc.). Due to such electrophysical characteristics of blood, the system of its arteries and capillaries may well play a key role in propagation of polarization waves through the tissues of body and cortex of cerebral hemispheres. Moreover, high rate of rotational relaxation of water and the formation of polarized domains-clusters in the network of its hydrogen bonds ensure propagation of displacement currents and polarization waves through blood vessels at the speed of light divided by the refractive index of water (~1.3).

The usual ECG spectrum reflects the dynamics of changes in the direction of main dipole of the heart and its main components, which correspond to structure of the blood pulse wave. At level of arterioles and capillaries in the brain parenchyma, the pulse wave modulates the dynamics of interstitial fluid (ISF) and causes fluctuations in intracranial pressure [14]. The pulse wave, in turn, is modulated by oscillations of the electric polarization of the blood [11, 15], which generate correlated ensembles of current dipoles of the conducting and contractile cardiomyocytes of left ventricle [12]. It can be assumed that correlations of electrical potential oscillations in ISF and cardiomyocytes, together with autonomic system of nervous interconnections of the heart and the brain, are involved in mechanism of neurovascular communication, which ensures an increase in blood flow to the brain regions involved in thinking [16, 17]. The neurophysiology of thinking is based on bioelectrical activity (BEA) of the visual and auditory nervous systems. The solar factor of evolution determined the dominance of vision in the hierarchy of nervous system of mammals and humans [2, 7]. Hearing played a key role in the genesis of the neurophysiology of articulate speech, which provides the initiation of the act of thinking and subsequent assessments of reliability and novelty of its result.

2. Methods and materials

The electrical activity of the heart and brain was measured using an Encephalan-EEGR-19/26 electroencephalograph with a sampling rate of 250 Hz. The device allowed timing the vibration frequencies (ν) from 0 to 100 Hz and the amplitudes of electric potentials in the range from 0 to 0.5 mV. It is known [2, 18] those sensory receptors transmit information to the brain by varying the AP repetition rate. ν-Spectra are also sensitive to changes in the intensity of local cerebral circulation [6], therefore, only ν-spectra of ECG and EEG were used for analysis with averaging frequencies at intervals of 5 sec. From the standard scheme of potential derivation 10–20, 4 points were selected on the left (F3, C3, P3, O1) and on the right (F4, C4, P4, O2), the reference electrodes were attached to the earlobes, and the ground electrode was attached to the forehead. For timing ν of the heart, electrodes were placed on the wrists at the point of a distinct pulse. The contact area of all electrodes was ~0.7 cm^2.

Singing in an undertone in the upper (nasal) and lower (chest) registers was used, the ears were plugged with thumbs, while latex gloves were worn for electrical isolation. The music was listened to through in-ear headphones (JBL C100SI). The volume of music playback in the headphones was adjusted to a level close to the volume of singing with the ears plugged. We studied the effect on the ν-spectra of the ECG and EEG of the presence in the blood of alcohol (100 ml of 40% whiskey) and high blood pressure (160/100). The experiments involved five normal hearing subjects (4 male and one female) with a median age of 50 years participated voluntarily in the study. In most experiments, Kholmanskiy (Kh) took part, similar results were shown by experiments with the participation of other subjects.

3. Results and discussion

ν-Spectra of EEG and ECG are given in Fig. 1 and Fig. 2. The value of ν varies in the range from ~4 Hz to ~30 Hz and reacts to external factors and changes in the subject's state. Plugging the ears with fingers, in contrast to headphones, turns the outer ear canal into a sound acoustic resonator-emitter and increases the sound pressure on the eardrum and cochlea [20, 21]. It is known that the main frequency of vibrations of the vocal cords in men is ~130 Hz, and the range of hearing sensitivity is from 16 Hz to 20 kHz. When the length of the outer ear canal is ~2.5 cm, the resonant frequency of air oscillations is ~3 kHz [22], and hearing has the maximum sensitivity there. Bone conduction of sound plays a significant role in the functioning of the auditory system [21]. It provides direct excitation of oscillations of the basilar membrane of the cochlea mediated by the electric potentials of endolymph and perilymph [23], which leads to an increase in the amplitude of deviations ν from the midline in EEG and ECG spectra when singing with closed ears (Fig. 1A) compared to listening to music and vocals through headphones (Fig. 1B). In the latter case, the changes are weakly expressed on EEG spectra and are completely absent on ECG during the transition from the state of relaxation to listening or when the piece is replaced (Fig. 1B).

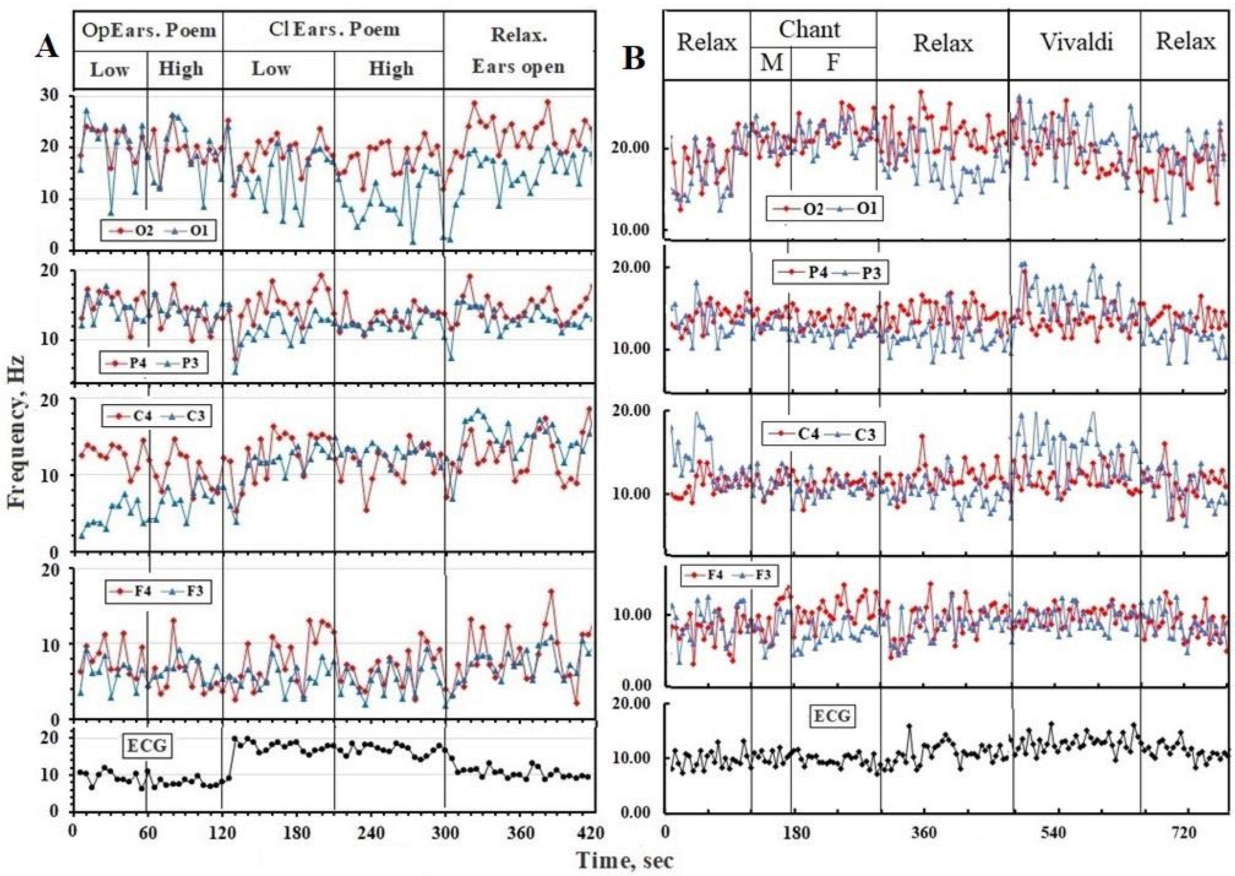

Fig. 1. Spectra of EEG and ECG for Kh. **A)** With closed eyes, chanting the prayers of *Our Father* and *Warrior of Spirit* (*Lord Jesus Christ strengthen me with Holy Spirit*) [19]) with open (OpEars) and plugged (ClEars) ears in a high (High) and low (Low) voice. **B)** Listening to the Psalms (Chant) *Christ is Risen* performed by the male choir (M) and *Dormition of Most Holy Theotokos* by the female choir (F), and the Vivaldi concert (*The Seasons, Summer*) through headphones. The eyes are always closed on A and B.

Headphones can change the frequency spectrum of sound waves in the outer ear canal due to its shortening [20-22] and their effect of earplugs greatly reduces the efficiency of sound transmission from the outer ear canal to the skull bone [21, 24].

The frequency in EEG and ECG spectra varies in the range of 8-13 Hz, which refers to the basic rhythm of brain electrophysics (α-rhythm), which dominates with the eyes closed [3]. Pacemakers of the α-rhythm are found in the thalamus, suprachiasmatic nuclei and are closely related to vision. It is believed that the nature of the α-rhythm is genetically related to ν standing electromagnetic Schumann wave in a spherical resonator between the Earth's surface and its ionosphere [25]. Synesthesia of vision with hearing [7] may be responsible for an increase in ν by ~2 and ~1.5 times at points (O2, O1) and (P4, P3), respectively (see Fig. 1A and Fig. 1B). The BEA of the visual areas of the cerebral cortex and the nuclei of lateral and medial geniculate bodies of the thalamus are projected onto these points [7], which are part of visual and auditory nervous systems.

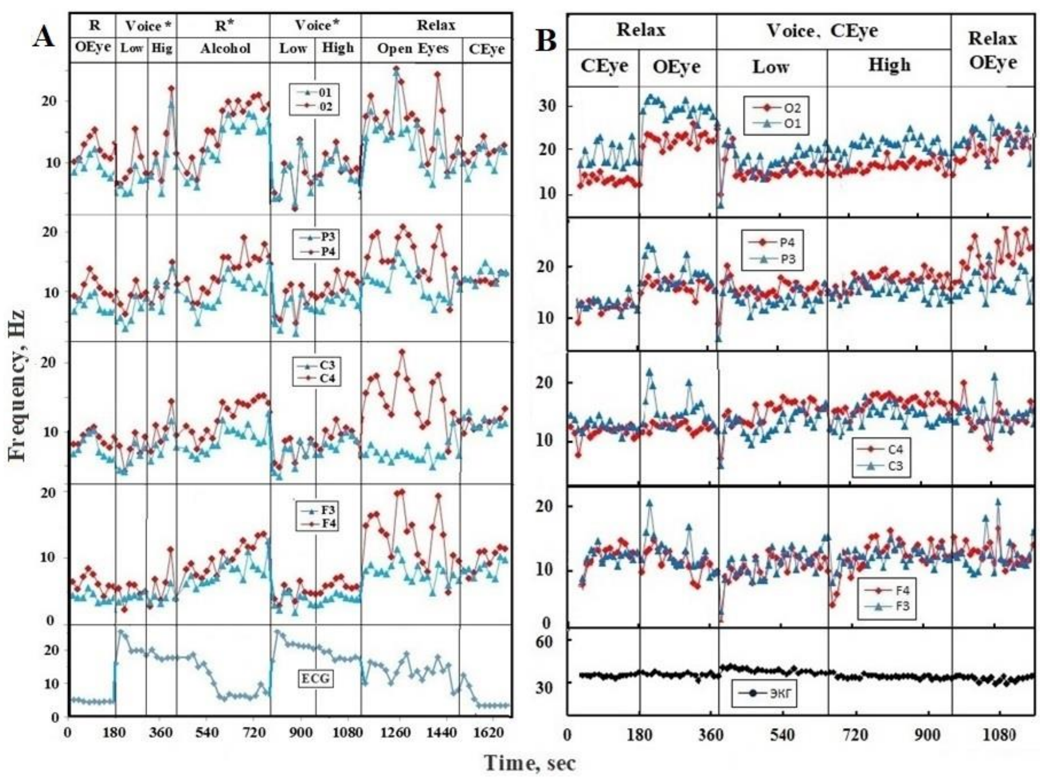

Fig. 2. Spectra of EEG and ECG Kh. **A)** Alcohol - taking for 440 seconds; CEye and OEye closed and open eyes, Voice - singing prayers in a low (Low) and high (High) voice, R - relax; *) - with closed eyes. **B)** Blood pressure 160/100; CEye and OEye closed and open eyes.

A significant drop in ν is observed with an increase in the amplitude of its deviations at point O1 compared to point O2 when singing with closed ears, and especially at high frequencies (Fig. 1A). This can be associated with an increase in the effect of bone conduction of sound on the visual system in the left hemisphere due to the localization of the speech center in the right-handed hemisphere.

The frequency values of ECG spectrum from ~5 Hz to ~35 Hz in Fig. 1 and Fig. 2 can be associated with the activity of correlated ensembles of left ventricular cardiomyocytes, which leads to polarization of the corresponding areas of the myocardium and is manifested on the amplitude ECG by the QRS complex and the T-prong [12]. Prong T reflects the process of ventricular repolarization and has a duration of 0.1-0.25 s. In the QRS complex, a positive R-prong characterizes excitation of the bulk of ventricular myocardium, and a negative S-wave reflects excitation of their basal regions. The duration of these prongs is one third of the time of the entire QRS complex (0.06-0.1 s [12]), that is, from ~0.02 s to ~0.03 s. These oscillations of the current dipoles of left ventricle will correspond to frequency of polarization waves of the water base of arterial blood in arterioles and capillaries of brain parenchyma from ~4 Hz to ~50 Hz. Metabolism of cerebral cortex significantly depends on water metabolism, which is limited by throughput of protein channels from aquaporin-4 in capillary membranes [14]. The electrophysical mechanism of these channels' operation requires a certain orientation of the water dipoles. It can be assumed that oscillations of polarization of water molecules in the blood of capillaries will facilitate escape of water through their aquaporin channels.

A small dose of ethanol led to a twofold increase in baseline frequency of brain with eyes closed, and more in right hemisphere than in left, and this effect is significantly enhanced with open eyes (Fig. 2A). This result is consistent with the data of the work on the increased effect of ethanol on metabolism of right hemisphere [26]. On the contrary, vocal factor with closed eyes almost completely negates the effect of ethanol on the heart and brain (Fig. 2A), which confirms genetic link between the base frequency of the brain and vision. These effects of ethanol are realized mainly due to changes in the tone of vessels of the heart and brain, on which blood pressure strongly depends. Indeed, similar changes in EEG and ECG spectra are observed at high blood pressure (Fig. 2B). Moreover, in this case, base frequency of the brain and heart increases, and especially at points (O2, O1) associated with the activity of the visual areas of the cerebral cortex.

4. Conclusion

A comparative analysis of the dependence of the frequency spectra of EEG and ECG on the physical state of body and excitation of auditory system with open and closed eyes, the sounds of one's own voice and vocal-instrumental music showed a direct relationship between activity of cardiomyocytes and neurophysiology of visual and auditory systems of brain. The physical mechanism of this connection was based on the modulation of trophic and signaling function of neuroglial system of the brain by frequencies of electric polarization waves of the water base of the blood of arterioles and capillaries in brain parenchyma.

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