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THE EFFECT OF HIGH-FREQUENCY ELECTROMAGNETIC RADIATION PARAMETERS ON THE ACTIVITY OF THE MONOAMINE SYSTEM IN LIVING ORGANISMS

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Abstract. Since the last century, due to the widespread application of Electromagnetic Radiation (EMR) and its spread, the special term "electromagnetic pollution" was adopted by the World Health Organization. The exception of the complete harmful effect of EMR on the human body and nature in general is not realistic as it seems. However, the study of the mechanisms of this factor's effect on biological objects remains in the interest of many scientific directions. In this article, the aim of the study is to investigate the changes of the monoamine (MA) ergic system in different structures of the brain under the low-intensity modulated and unmodulated, single and long-term effects of electromagnetic radiation (EMR). After studying the behavior and memory processes of rats under the influence of EMR, the amount of 5-HT (serotonin) and catecholamines was determined by biochemical methods, and at the same time, a comparative analysis of lipid peroxidation processes and functions was performed. The cumulative effect of the long-term effect of low-intensity modulated EHF EMR is quite weak, and a single application of EMR for 30 minutes is more effective. This fact is manifested in the activity of the MA-ergic system of the cortical and subcortical structures of the brain, as well as at the behavioral level. The effects of low-intensity EHF EMS on neural processes depend on the radiation duration and the modulation parameters. The effect of EEG modulated EHF EMR in the alpha range is more effective in terms of the analysis of neural processes, and these neurophysiological effects are recorded at a radiation power of 10 mW/cm^2. The detection of functional changes of the cerebral cortex in the norm and during the influence of EMR can be used in the development of hygienic norms in different radiation ranges. This, in turn, opens promising ways to solve the problem of remote control of the state of the CNS with the help of the amplitude-frequency and modulation parameters of the EMR.

Keywords: *Electromagnetic radiation, monoaminergic system, biochemical analysis, brain.*

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1. Introduction

The human body carries out its vital activities with various complex processes, in particular, with intracellular and extracellular electromagnetic information and bioelectrical regulation. Thus, the technogen electromagnetic environment is considered a real radiation source for the human body and bioecosystems (Hossmann *et al.*, 2003). In this regard, the study of the problems of interaction and influence of the bioelectromagnetic

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system with living nature, technical EMR sources is one of the actual researches. In the literature, there is a large number of information and extensive judgments about the intensity and safety of the impact of EMR on biological ecosystems and the human body (*Bielski*, 1994). In the process of evolution, living organisms not only adapted to the constant effects of electromagnetic fields occurring in nature, but also used them as information transmitters, which made it possible to ensure mutual relations between cells and the biosphere. Currently, the study of the problem of the effect of low-intensity EMR on living organisms requires comprehensive studies at the most diverse levels: from molecular, cellular to behavioral responses. (Adayev *et al*., 2005; Adey, 1986). Currently, the study of low-intensity EMR effect in the EHF range, which is considered a potential threat to human and animal bodies, is of special interest. This is due to the fact that, in the objects corresponding to the linear dimensions of the wavelength in the specified range, the resonance effect occurs more quickly, and as a result, it leads to an increase in the absorption of radiation energy (Chokroverty *et al*., 1995).

If we agree with the opinion of the researchers, the response of biological objects to the impact of EMR is divided into three groups: inadequate energrtic, energetic-information and information. The energetic response is usually caused by high-intensity EMR exposure and is higher than the body's energetic demand (Chokroverty *et al*., 1995; Heitanen, 2000).

Based on the ideas that, the level of excitation of the neuronal membrane corresponds to the activity of energetic processes occurring in neurons, it would be natural to assume the existence of a relationship between the activation of neural processes in the brain and the activity of LP processes. Along with the experimental facts that biogenic monoamines can affect the generation of active metabolites of oxygen in the cell, free radicals also act as antioxidants by influencing the reactions. The detection of the dynamics of the functional changes of the cerebral cortex in the norm and during the effect of EMR can be used later for the development of hygienic norms in different ranges of EMR. In addition, on the basis of the obtained data, an adequate selection of the EMR can be carried out, which creates one or another tendency in the functional states of CNS. This, in turn, opens promising ways to solve the problem of remote management of the state of the CNS with the help of amplitude-frequency and modulation parameters of the EMR (Heitanen *et al*., 2000).

2. Experimental part

The main goal of the research is to study changes in the amount of biogenic monoamines in individual brain structures caused by low-intensity EMR in adult white rats and to study the effect of these changes on congenital and later acquired behavioral responses. For the duration of the experiment, the animals are placed in a special transparent chamber. Using a GKCh-60 generator (Russia) as an EMR source, the output signal was modulated in the range of the EEG alpha rhythm. The used EMR parameters EHF ≤ 10 mW/cm^2, 41.7 GHz are determined on the basis of laboratory studies. In the main experiments, single (for 30 minutes) and long-term (30 minutes for 5 days) irradiation of modulated and unmodulated EEG with the EHF EMR alpha range was used.

After exposure to EMR on experimental animals, the biochemical method was used to determine the amount of 5-HT and CA in the VC, LC and subcortical structures of the hippocampus and hypothalamus of the brain. To determine the amount of monoamines, the brains of control and EMR-treated animals were removed from the cranium within 2 min after decapitation, frozen at -2°C, and then placed on ice (other steps of biochemical analysis was also performed on ice), separating the above structures and placing them on aluminum foil, and the specific gravity of the sample has been determined.

For the biochemical determination of monoamines, the fluorimetric method was used (Kogan & Nechaev, 1979), since this method allows the fluorimetric determination of serotonin and catecholamines in one sample. Fluorescence intensity was measured on an MPF-4 spectrofluorimeter. The amount of monoamines was determined by comparing the fluorescence intensity of samples obtained using standard solutions with the difference between the fluorescence intensity of experimental and control samples.

3. Results and discussion

Despite the fact that, the theories about the components of the MA-ergic system have been known since the middle of the last century, though the dark points were clarified by studying the effects of 5-HT and catecholamines at the level of cells and brain tissue in the research conducted in this direction, the presence of controversial points in the obtained results leads to further improvement of the scientific activities conducted in this direction. It is known from literature sources that, serotonin (5-HT) was first discovered in blood in 1948, and in central nervous system tissues in 1953-54 (Cadogan *et al*., 2001). Despite the fact that, 5-HT affects the regulation of thermal energy and the endocrine system in the body, the activity of the cardiovascular system, appetite, sleep, sexual behavior, the maintenance of the body's immune system and adaptation processes, the most effects have been studied on the CNS.

The synthesis of CA mainly occurs in the nerve cell, which has the dopamine-beta-oxidase enzyme, and begins with the capture of tyrosinamic acid. Tyrosine hydroxylase and DOFA-decarboxylase enzymes were detected in the axoplasm of the cell, and DA-beta-oxidase enzyme along with NA was found in the vesicles. With the participation of these enzymes, a chain of biochemical processes takes place, consisting of the conversion of tyrosine to NA, and successively DOFA, DA and NA are formed. The need to analyze the mechanisms of low-intensity EMR effects on the body, primarily on the CNS, suggests the need to find effective methods for evaluating the activity of the brain's ergic systems. It is known that, the balanced activity of these systems ultimately determines the body's adaptive responses to external influences. According to the researchers, the wide and rapid development of the study of the biological effects of EMR comes from the public demand of our modern society. In these studies, the analysis of the regularities of the changes that may occur in different departments of the CNS against the influence of low-intensity EMR remains an actual and at the same time less-studied problem. Taking into account what has been said, the main goal of the study was to investigate the role of MA-ergic neurotransmitter systems in the formation of low-intensity EHF EMR effects on neural processes (Aghayeva, 2022).

Summarizing the issues we have considered, it can be said that, emotional stress affects the physiological systems of living organisms and is reflected in multifaceted system reactions. An attempt to connect the processes taking place in the external environment with the changes in the functions and structures of various vital systems of the organism that lead to changes in the character of the relationship with the environment as a whole is one of the important stages of the analysis of the factors influencing the development of adaptive behavior at different stages of ontogenesis.

Low-intensity EMR is widely used in the treatment of a number of other diseases. For example, oncological, blood-vascular pathologies, respiratory diseases, surgical profile pathologies, etc. During the treatment of eye diseases, a qualitatively important result was obtained, as the “secondary” effective therapeutic effect of several frequency fields of mm-band electromagnetic radiation with a wavelength of 5-6 mm using the skin-effect method was revealed. At this time, as a result of the effect of EMR on the eye or the occipital part of the brain, the stomach ulcer was cured (Chernov, 1989).

As mentioned above, subcortical structures play an important role in the development of cognitive functions and neuroendocrine regulation. In this regard, the cortex and subcortex of the brain (in particular, the hippocampus formation) have been attracting the attention of cardiologists, endocrinologists and neurologists for a long time. This is due to the fact that, the development of neurodegenerative processes occurring in brain structures is the basis of the weakening of cognitive processes and affective states associated with arterial hypertension, diabetes, Alzheimer's disease and normal aging. It should be noted that, in recent years, the biological effect of EMR effect has been studied more in terms of biochemical, biophysical, genetic changes of cells and intracellular systems. At the same time, the solution to this problem is known in the literature related to the effect of EMR on the body and its functional systems, the effect of some parameters of EMR on the functional state of the CNS of humans and living organisms, the intensity parameter, modulation and time dependence of radiation.

The need to analyze the mechanisms of the effect of EMR on the body, first of all on the CNS, is the need of the day to find an effective method of assessing the activity of endogenous systems of brain. It is their balanced activity that ultimately determines the body's adaptive response to external influences (Chichnadze, 2002; Frey, 1993).

It is also known from the literature that, the activity of the components of the MA-ergic system during EMR has a phasic effect. Thus, the level of EMR depending on the time at the 30-minute effect, the disruption of the training process and the activity nature of the 5-HT-ergic system increasing on both at the level of dynamic indicators and biochemical analysis the similarity of the direction of changing the amount of NA along with 5-HT in the cortical areas of the brain, reveals the physiological mechanisms of the actualization of adaptive processes and the fact that the effect of 5-HT is in the rising phase.

Thus, as seen in Fig. 1, it is known from the research materials obtained by us that a single exposure to low-intensity EMS for 30 minutes leads to a change in the activity of the 5-HT-ergic system of the brain. The nature and validity of these changes depend on the physical parameters of the waves we use and the structures of the brain being studied.

During long-term EMR, the deterioration of the training process and the decrease in the amount of NA along with 5-HT indicate the actualization of the inhibition processes in the brain, which determines the phase of the decrease in the activity of the components of the MA-ergic system. A one-time EMR effect, along with the disruption of the training process in the modulated parameter, changes the behavior, along with the dynamic and quantitative indicators of the 5-HT-ergic system, the rise of the NA-ergic system in a parallel form shows that the process changes in a wave form (Mamedov *et al*., 2009).

Thus, the activity of the 5-HT- and NA-ergic system during EMR has a non-linear characteristic, making it difficult to regulate the activity of these systems with external interventions. Nevertheless, studies have shown that the activity of DA-ergic system has a linear characteristic in the hypothalamus. If it is considered that intervention in linear variable systems in medical fields and regulating the operation of a system with such a feature is of more interest, it is considered appropriate to use drugs with selective effect on the activity of DA-ergic system when it is necessary to intervene in the activity of the modulator system during high emotional tension generated in excited states (Homberg et al., 2007).

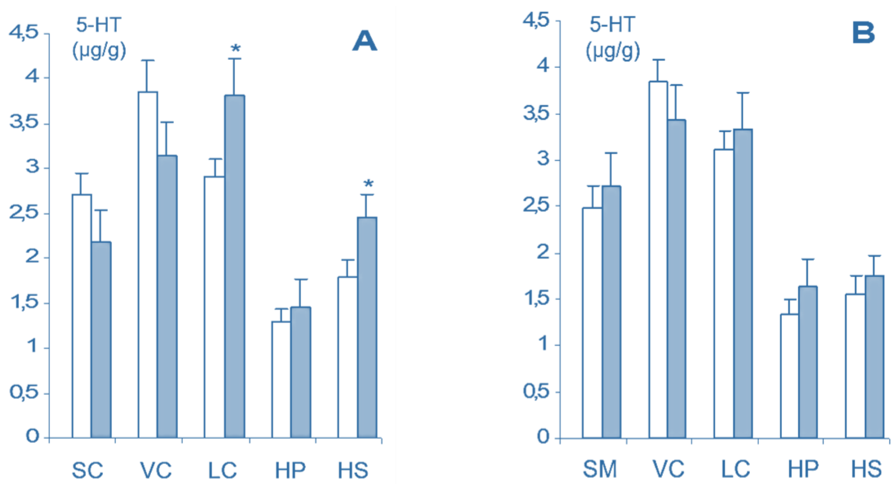

Fig. 1. The effect of a single application of modulated (A) and unmodulated (B) low-intensity ultra-high-frequency electromagnetic radiation for 30 minutes on the amount of 5-HT in the cortical and subcortical structures of the brain. SC- sensorimotor cortex, VC-vision cortex, LC-limbic cortex, Hp – Hippocampus, HS- hypothalamus, 5-HT-hydroxytryptamine (serotonin). White columns – control, black columns – experiment

Apparently, it is not correct to unambiguously evaluate the participation of monoamines in the regulation of learning and memory mechanisms at different levels of the EMR effect. Thus, when looking at the obtained data in a complex way, it is clear that, the difference of the training process from the control at different parameter impact levels of the EMR shows the limit of the adaptation possibilities of the organism in different life conditions (Aghayeva, 2022).

By comparing the obtained data, we can come to the conclusion that, monoaminergic regulation in the neocortex area of the brain does not always follow the regularity known to science (Grinyaev *et al*., 1999). Nevertheless, the known interaction in the hippocampus (intact) and subcortical area (only between 5-HT and NA) remains valid. On the other hand, it is clearly observed that, the determined in the first minutes of exposure of NA has the same direction of variation in the functional areas. As a result of the increase in emotional tension depending on time, it leads to a difference in the direction of NA activity in the mentioned areas. This shows that, MA-ergic regulation of functional systems differs at high levels of emotional stress. From here, it can be suggested that, the diversity in the MA-ergic regulation of functional systems during strong stress destroys the activities of these systems based on the hierarchical principle (Agaeva *et al*., 2010). Depending on the duration of EMR exposure, it was recorded that the learning process was disrupted. It is during the initial effect of EMR that the quantitative indicators of monoamines in the cortical areas of the brain also changed. It is known that, learning and memory processes deteriorate sharply during a sharp decrease in the activity of monoamines. This indicates that, the inhibition mechanism of excitatory centers is already activated in the hypothalamus. As a result of EMR in the hypothalamus, the variability of the amount of DA was different from the activity of other MA, as well as its activity in the cortical areas and the hypothalamus. Thus, the decrease in the amount of DA in the hypothalamus due to the effect of EMR is reflected in the literature, it is shown that, DA-ergic neurotransmission has an intermittent character as the main reason for the deficit of DA in the hypothalamus. On the other hand, it is shown that, DA has an inhibitory effect on the main emotional arousal nuclei located in the hypothalamus as well as participating in the secretion of specific hormones of hypothalamic cells (depending on the receptor located in the membrane) (Aghayeva, 2022).

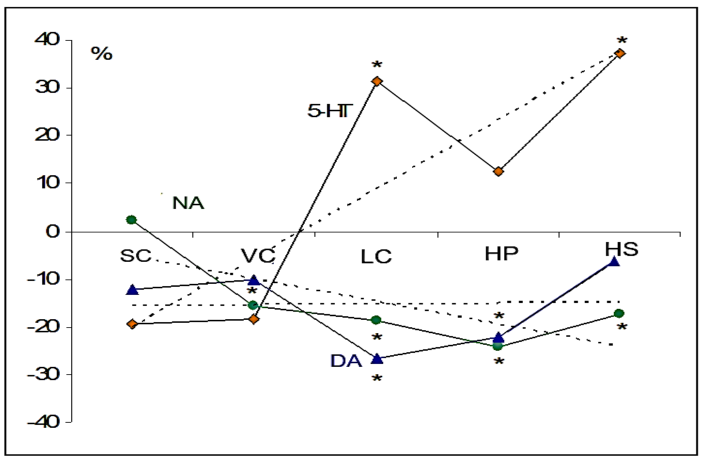

Fig. 2. Comparative analysis of the dynamic properties of the MA activity gradient in the cortical and subcortical structures of the brain (under the conditions of a single exposure of low-intensity modulated EHF EMR for 30 minutes). Dotted – linear approximation. * - $P \leq 0.05$

It can be concluded from the conducted research that, it is possible to register the neurophysiological effects of EHF EMR at the radiation intensity of 10 mW/cm^2. The neurophysiological effects of such low-intensity radiation can be obtained only at low levels of emotional stress and modulation of the leading frequency of the EEG in the alpha range. As a result of the influence of low-intensity EHF EMR, the changes occur in the innate behavioral responses of adapted animals, but the characteristics of these changes depend on the parameters of the applied EMR. Unlike long-term radiation, the changes in innate behavioral responses during a single exposure of EEG in the α-range of EHF EMR are more sharply expressed pronounced (Mamedov *et al*., 2009).

As can be seen from Fig. 2, individual components of the MA-ergic neurotransmitter system (5-HT, NA and DA) in the cerebral cortex and subcortical structures are differentially affected by a single use of 30 minutes, in contrast to the long-term effect of EHF EMR. In this case, there is a reciprocal relationship between 5-HT and DA (Mamedov *et al*., 2010).

4. Conclusions

Thus, low levels of emotional stress lead to attenuation of newly acquired behavior and enhancement of innate behavior in rats. On the other hand, the time-dependent deepening of the effect of low-level emotional stress, the violation of the evaluation of the probability of the irritating stimulus, leads to the inversion of behavior. At low levels of the duration of the effect of low-level emotional stress, the conditioned reflex acquired on the basis of innate behavior does not affect the activity, but only leads to a change in the frequency of behavioral acts. Thus, based on the obtained facts, it can be said that, depending on the parameters of the impact of low-intensity EHF EMR, the low-level emotional stress disrupts the formation of new functional systems and, at the same time, fixation mechanisms, and increases the likelihood of danger assessment. The conducted research once again proved the negative effect of low-intensity EMR on living organisms, especially on training and behavior (Agaeva *et al.*, 2011). Thus, depending on the duration of the effect, the facts such as the disturbance of memory processes and the change of the level of emotional stress, for the purpose of protecting human health, make the need of necessity to conduct complex researches and the requirement on carring out of an appropriate measures plan.

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