Techniques and instrumental complex for research of influence of microwaves encoded by brain neural signals on biological objects’ psycho physiological state

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Abstract. New instrumental technique for research of the psycho-physiological reactions of the bio-objects under the microwave electromagnetic radiation, modulated by interval patterns of neural activity in the brain registered under different biological motivations, are suggested. The preliminary results of these new tool tests in real psycho physiological experiments on rats are presented.

1. Introduction
The Russian Science Foundation announced that for the next decade, one of the Russian science development priorities is the problem of "Neurotechnology and cognitive studies". One of the most important tasks is defined as "the Study of fundamental brain mechanisms and cognitive functions with the use of new methods for directed modulation of neural activity and brain functions. This assumes the creation of new methods and tools for electromagnetic non-invasive brain stimulation, regulating the activity of neurons in the brain using implantable devices. The relevance of these works is determined by the possibility of experimental studies of brain function fundamental mechanisms and a wide range of applications ranging from medicine, pharmacology, and psychiatry to special applications. It should be noted that such studies have started more than half a century ago and widely developed with the use of miniature microelectronic biotelemetry systems that allowed them to influence the biological object and at the same time to record his physiological parameters in free behavior [1,2]. Among the outstanding works on remote effects on the biological object to control its physiological state, motivation, and behaviour, it is necessary to note the work of the Spaniard José Delgado, a pioneer of the electrodes implantation into the brain [3], and studies of V. M. Arbutin, one of the Russian biotechnical systems founders [4]. In these works, the radio channels were used for the transmission of stimulus signals to the implanted electrodes in different brain structures, and information about physiological parameters of biological objects was received for analysis in the opposite direction. Such studies are continuing on the basis of modern micro- and nanoelectronic technology and are essential for the brain mapping, the reconstruction of its functional system, neural interfaces development, including new types of non-invasive human-machine interfaces (EEG, EMG, eye movement, etc.). Another modern method of a non-invasive impact study on the brain is directly related to electromagnetic fields (EMF) exposure on biological objects. Great attention is paid to this problem in recent years, due to continuously growing electromagnetic pollution of the environment. So, mankind concern about its electromagnetic safety. Adequately systematized research work and results in this direction are proposed in the review of the International Commission for the protection
from non-ionizing radiation (ICNIRP) [5], and in the following analytical publications [6,7]. An important result of these studies was the person's individual sensitivity detecting even to weak microwave electromagnetic effects [8]. In particular, the relation between the dose and heart rate variability (HRV) [9], and a number of psychological characteristics [10]. This allowed us to formulate the first basic principle of constructing a new methodology and tool, namely, low-intensity microwave electromagnetic radiation absorbed in a thin layer of the skin, causing excitation of the central nervous system - CNS via the receptor apparatus of the skin and peripheral sensory receptors. This stimulation of the CNS is transferred to the basic functional systems of the organism, in particular, changes of HRV and some of the psychophysiological characteristics of the person. The second basic principle is related to the results obtained in [11] and consists in the fact that: the neural activity of different brain structures of experimental animals depends on the prevailing motivation. Temporal patterns of the brain neuron impulse activity reflect the specificity of different motivational states, including hunger, thirst, fear, or aggression, as well as the satisfaction of these motives. The combination of the microwave modulation controlled on the bio-object with a temporary pulse (spike) patterns of brain activity with simultaneous monitoring of several physiological parameters, including behavioral, the foundations of a new research method and the devices proposed in this work.

2. The research methodology

Above were indicated the basic principles of the developed methods and devices to study the effect of the pulsed microwave radiation on biological objects' cognitive function. Let's look at these principles in more details.

1.1. Neurons information codes

In the laboratory of "Functional systems" (P. K. Anokhin Institute of Normal physiology) under the supervision of Professor, Ph. D. Zhuravlev B. V. (one of the authors of this article) was carried out the complex of investigations aimed at the analysis of the inter-spike intervals distribution of neural activity in different brain structures of an animal (rabbit, rat) in his free behaviour and different motivational states. For the experiments, we used both traditional glass microelectrodes [12] and microelectrode matrix in microelectronic application [13]. It was experimentally established on hungry animals that there is a bit of group activity in 12 brain structures (lateral hypothalamus, ventromedial nucleus of the hypothalamus, reticular formation, thalamus, sensorimotor, visual, orbital area of the cortex, hippocampus, etc.). This group of neural activity is characterized by the dominant interspike intervals distribution. As an example, figure 1 shows inter-spike activity and the distribution of the interval pattern neurons of the lateral hypothalamus at the hungry animal.

![Figure 1. Inter-spike neuron activity and histogram of the inter-spike intervals distribution.](image)

The interval histograms are dominated in the range from 5 to 10 ms and 150 ms. Similar studies in other motivational animal’s states (thirst, immobilization, etc.) showed "carrier frequency" corresponding to the 150 ms interval is stored, and the intervals characterizing the motivations change significantly. Thus, all three mentioned specific motivations varied at small intervals between the discharges but had a "carrier" frequency 150 ms, which coincides with the theta - rhythm in the EEG study. This rhythm in the EEG exists in animals and humans during intense, stressful conditions. Further studies have shown that after a satisfaction of all three motivations, there is a reorganization of the interval pattern from group activity to a regular single type, and at the histogram, one interval begins to dominate. For the "hunger" motivation source such a reorganization of neural activity during eating is illustrated in figure 2.
Figure 2. Reorganization of the interval activity pattern of the neuron when animal ate: 1 - the activity of the neuron; 2  - thick line – the beginning of food eating; 3 - timestamp (250 ms); 4 - the neuron activity interval histogram of the hungry animal; 5  - The histogram of the interval activity of the neuron when animal ate.

Thus, as the encoding principle of the stimulating microwave radiation in the developing instrumental complex is proposed to use temporal inter-pulse interval patterns in the neural activity of the brain, during different biological motivations.

1.2. Effect of weak electromagnetic fields on the person’s physiological parameters

In recent publications, the authors of this paper [14,15] examined the results of development and application in psychophysiological studies in humans of hardware and software complex for the rapid assessment of the individual effects of weak microwave radiation on heart rate variability of man and a number of psychophysiological parameters. In these works, it was shown that human sensitivity even to weak microwave fields depends on the initial physiological state and health, in particular from the background frequencies and the stability of the heart rate. In addition, subjects with poor health, low activity and mood, high situational and personal anxiety (according to the preliminary psychological tests) were observed more expressed changes in the cardiovascular system. An example of the weak microwave field action (energy flux 50 mW/cm$^2$; frequency - 930 - 960 MHz, irradiation time was 6 min and the absorbed dose of 110 J/kg) on HRV is shown in figure 3, which shows examples of pulse interval distribution histograms before and after microwave exposure.

Studies of changes in the performance during carrying out complex tests in a group of 25 volunteers in the process the same as the impact of non-modulated EMFs have shown that in 12% of subject’s performance indicators did not change and more than 50% of these indicators deteriorated significantly [16]. In [17,18] it was reported about the higher sensitivity of biological objects to modulated fields and resonance phenomena in the functional system of the body, including the CNS, can lead to a significant strengthening of its response to modulated effects, synchronized with biological processes [19].

Thus, in the proposed research methodology affecting microwave electromagnetic field is the physical information carrier encoded with the inherent brain patterning motivation of the biological object, and, even low exposure can lead to synchronous changes of neural activity, and therefore, motivation and behavior of the biological object. Such opportunities are the cornerstone for the further studies. It should be noted that when such studies involving human subjects must ensure a number of moral and ethical standards and safety requirements. Therefore, initial studies under the new methodology were carried out on experimental animals, in particular, on 10 male Wistar rats, in compliance with the principles of humanity set out in European community Directive (2010/63/EU).
3. The instrumental complex
The proposed research methodology determined the structure and composition of the new instrumental hardware and software complex, shown in figure 4.

1.3. The main components of a tool set
Unit 1 - Experimental chamber (box) with a lab rat. We used Rat Touch Screen Chamber of the American company Lafayette Instrument where the animals were previously trained to eating and drinking instrumental skills. Photo of the camera is shown in figure 5. The camera is equipped with a video camera that captures moving rats; touch screens, through which the animal gets food and drinking by himself. Implanting into the peritoneal cavity of the rat miniature biotelemetric capsules, it provides a permanent cardio signal recording even under the action of external EMFs.
Figure 5. Photo of the experimental chamber with rat animal.

Unit 2 - Imitator. In the background of the figure 5, the antenna of the generator (imitator), providing the irradiation of biological objects with modulated microwave EMF, has been shown. A photograph of this block is demonstrated in figure 6. External digital control of radiating power and microwave signal modulation were provided by using digital potentiometers (type AD5204). The imitator operates in five frequency bands from 0.9 to 2.4 GHz.

Figure 6. Photo of the imitator (generator) of EMF.

Unit 4 - microwave dosimeter. This new device allows controlling some basic dosimetric parameters, such as the flux density of the incident microwave energy (EFD, W/cm²) and specific absorption rate (W/kg); specific dose absorbed energy (J/kg) [20]. In figure 7: a) photograph; b) the principle of operation of the microwave dosimeter.

Figure 7. a) The photo of the microwave dosimeter; b) The principle of the device operation.

The principle of operation: 1 and 2 - microwave sensors; 3 - biological tissue phantom; $P_{in}$ - falling energy flux; $P_{out}$ - passed energy flux; $P_{refl}$ - reflected energy flux; $P_{abs}$ - absorbed energy flow. In the
absence of microwave radiation, the voltage between sensors 1 and 2 equals zero. When electromagnetic radiation appears, a differential voltage arises, due to absorption in the material layer. This voltage is the quantity that characterizes the absorbed dose of microwave radiation. Blocks 3,5 control all units of the complex, collection and preliminary processing of information from all measuring devices. Unit 6 (remote computer) allows remote controlling the blocks.

1.4. Preliminary psychophysiological experiment results
The experiments were performed on 10 Wistar male rats in compliance with the humanity principles, set out in the EU Directive (2010/63/EU). Rats were exposed to microwave radiation with the values of flux density energy, corresponding to SanPiN 2.1.8/2.2.4.1383-03 requirements. The influence of EMF on nondeprived rats’ behavior and the behavior of rats after 24 hours food and drinking deprivation was investigated. The rats were placed in the box of hardware-software complex (Rat Touch Screen Chamber, Lafayette Instrument, USA) where they have previously trained feeding and drinking instrumental skills. As a result of experiments, it was shown that, depending on the duration of the systematic GSM band microwave radiation modulated with frequency typical for the motivation of thirst, there was a significant decrease in the drinking acts number (up to 50% of their initial values). The figure 8 illustrates these results. During 13-hour time-modulated GSM radiation, the number of drinking and feeding acts was decreased. The number of food-procuring behavioral acts was not significantly changed when exposed to electromagnetic radiation (EMR) for 1-4 hours. Hence, according to the results of the experiments, electromagnetic radiation, modulated with temporal patterns of the brain neural activity, affects the instrumental behavior of rats. However, it is necessary to increase the number of samples.

Figure 8. A number of drinking acts of non-deprived rats under the influence of modulated microwave radiation (associated with drinking behavior) for 2 hours. X axis shows different times of the day.

4. Conclusion
The proposed instrumental complex allows investigating the response of the central nerves system (brain) of experimental animals on the microwave electromagnetic radiation, modulated by interval patterns of neural activity in the brain, registered under different biological motivations. The preliminaries tests of this new method and instrumental complex in series of psycho-physiological experiments on rats have shown the changes in their drinking and food-procuring behavioral acts. The future experiments will be directed to the research of the experimental possibilities for remotely affected by microwave fields on cognitive functions of the brain, which are formed on the basis of the memory mechanisms, the dominant motivational states and evaluated by the results of the behavioral activity. Expected results of the research may have practical importance for medical rehabilitation and psycho-physiological patient’s correction.

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