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A MODULATED ELECTROMAGNETIC FIELD AS A FACTOR OF SELECTIVE INFLUENCE UPON THE MECHANISMS OF GOAL-ORIENTED BEHAVIOR IN ANIMALS

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[Article by K. V. Sudakov, Scientific Research Institute of Normal Physiolog[illegible] imeni P. K. Anokhin, USSR Academy of Medical Sciences, Moscow, dedicated to the 200th anniversary of the Department of Physiology, Moscow Order of Lenin and Order of the Red Labor Banner Medical Institute No 1 imeni I. M. Secheno[illegible]

[Text] The search for directed influences upon brain functions is traditionally associated with the use of various psychopharmacological agents. However, pharmacological influences have a number of undesirable side-effects, among which difficulties in determining their individual doses, the duration of the aftereffects, toxic effects, and so on are foremost. All of this forces us to seek new ways of dosed, reversible influence upon brain activity, devoid of the clearly pronounced shortcomings of pharmacological preparations. It is becoming more and more obvious today that selective impairments of mental activity similar in their manifestations to the action of many psychopharmacological agents can be observed when living organisms are subjected to extreme physical factors--mechanical irritation, temperature, a gas medium, acceleration, radiation, and so on. Among these factors, which have a significant influence upon brain functions, a speci[al] role belongs to modulated electromagnetic fields in the radio-frequency rang[e] (12-14,18-20,23-26).

The systems approach, functional system theory in particular, has been foun[d] to be promising in research on directed influences upon brain functions (1,3). In contrast to the situation in research on the influence of various extreme factors upon excitation and inhibition in the central nervous system, functional system theory raises the issue as to which key mechanisms of goal-oriented behavior (afferent synthesis, decision making, goal setting, assessment of the result) are influenced by the given factor.

Our task was to determine which units in the central architecture of animal goal-oriented activity are affected by a modulated electromagnetic field (MEMF) and the sequence in which this field acts. To answer this question we studied the effects of dosed MEMF in the following experimental situatio[n]

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1) Choice, by animals, between a feeding and an avoidance reaction in response to the same conditioned signal in a changing situation (E. A. Asratyan's switching principle (7)); 2) extinction of conditioned feeding reactions; 3) development and extinction of conditioned feeding reactions in a group of communicating animals; 4) choice, by the animals, of the side from which to obtain reinforcement in a T-maze; 5) self-stimulation reactions.

Dynamics of Change in Goal-Oriented Behavior of Rats in Response to MEMF When Offered a Choice Between a Feeding and an Avoidance Reaction to the Same Conditioned Signal in a Changing Situation

In order to study the influence of MEMF on development of the key mechanisms behind goal-oriented feeding and avoidance reactions, we built a special experimental chamber in which we could develop and study feeding and avoidance reactions in animals in response to the same conditioned triggering stimulus presented in different situations created by changing the color of the removable rear wall of the chamber (white or black).

An electric lamp and a feeder were on the left side wall of the chamber. There was a brass grating to which a voltage could be applied in the left part of the chamber floor.

The experiments were conducted in the following way. A conditioned feeding reaction was developed in the presence of a white chamber wall in rats which had first been starved for 24 hours. As a result of the training, in response to the light the animals rushed to the left half of the chamber where the feeder was located. Then the chamber's rear wall was replaced by the black wall, and electric current of threshold intensity (30-50 volts), eliciting an avoidance reaction in the rats, was applied to the grating in the left half of the chamber wall. Under these conditions, when the light stimulus was turned on, rats which headed for the feeder, in their accustomed way, received electrocutaneous stimulation, which they could avoid only by moving to the right half of the chamber. After two or three combinations of the light and electrocutaneous stimuli in the presence of a black chamber wall, the rats developed an avoidance reaction--that is, in response to the light the animals remained in the right, "safe" half of the chamber.

The developed reactions were studied in the presence of an MEMF created in the chamber by means of metallic plates secured to the front and rear walls of the chamber and connected to an EMF generator. The distance between the plates was 40 cm.

The EMF source was a UVCh-2 instrument modified in our laboratory by A. A. Lyubovnyy; used together with a ZG-10 acoustic generator, it created an EMF with a frequency of 39 MHz, sinusoidally modulated at a frequency of 50 Hz. Modulation depth was about 80 percent. In most experiments the intensity of the field inside the chamber was 30-120 w/m. The intensity of the electric component of the EMF inside the chamber was monitored with a diode voltmeter; intensity was determined using the formula $E=U/d$, where U is the voltage measured at the capacitor plates, volts, and d is the distance between the plates, meters. In addition we made control measurements of the EMF intensity using an IEMP-1 instrument.

G. D. Antimoniy (4) studied the particular manifestations of conditioned avoidance and feeding reactions in the presence of an MEMF using the described procedure in experiments on 28 rats. Initial training was terminated when the rats displayed 100 percent adequate reactions in response to 10 presentations of the triggering stimulus in the presence of a white chamber wall. As a rule, just exchanging the white and black walls itself elicited a distinct avoidance reaction in trained animals: The rats crowded themselves into a corner, hugged the chamber floor, and breathed faster. In subsequent experiments the developed reactions were analyzed in the presence of the MEMF.

In the presence of the MEMF, in 5-20 minutes the rats first experienced a disturbance in avoidance reactions. In response to the triggering stimulus, animals in the avoidance situation (black chamber wall) rushed persistently to the feeder despite the fact that they experienced an intense electrocutaneous stimulus (in this case the number of motor reactions towards the feeder in response to light attained an average of more than eight attempts in a single experiment; one animals made 24 such attempts). In the time during which the MEMF was present, replacement of the light wall by the black wall failed to elicit the avoidance reaction seen in intact animals. Feeding reactions in the presence of a white rear chamber wall in response to the triggering stimulus were the same as before. However, certain changes were revealed in the feeding behavior of the animals. Among trained intact rats, the reaction time to the triggering stimulus (the time between the moment the stimulus was turned on and the moment the rat pressed the feeder bar) was rather stable, exhibiting extremely insignificant fluctuations (5.7-6.6±0.08 sec). When the MEMF was present the fluctuations in the reaction time to the conditioning stimulus grew dramatically (3.2-9.9±0.3 sec). However, the difference in the means of the reaction times before and during irradiation turned out to be statistically insignificant. Arisal of frequent motor reactions toward the feeder in the interval between signals, which was practically not observed among intact animals, was also highly typical of short-term exposure to the MEMF. The noted changes in behavioral reactions following a 5-20-minute exposure to the MEMF were observed in 64 percent of the rats.

When the animals were exposed to the MEMF for a longer period of time, the changes in avoidance reactions described above were compounded by more highly pronounced and more diverse disturbances in feeding reactions (see table below).

Changes in Conditioned Reflex Reactions of Rats Exposed to an MEMF

Stage	Time of Exposure	Avoidance Behavior	Feeding Behavior
I	5-15 min	Disturbances in avoidance reactions of the animals in the choice situation	Increase in fluctuations of reaction time to conditioned stimulus
II	20-45 min	As above	Increase in reaction time to conditioned stimulus. Arisal of avoidance reactions in the "feeding" situation. Motor reactions toward the feeder failing to culminate in feeding.
III	45-60 min	Absence of a reaction to conditioned stimulus	Absence of a reaction to conditioned stimulus
IV	1.5-2 hours	Profound inhibition of general motor activity Absence of a reaction to direct nociciptive stimulation	Failure to chew and swallow food inserted in mouth

In order to reveal whether the noted disturbances in behavioral reactions in response to an MEMF are reversible or irreversible, we excluded 10 rats subjected to a 2-hour MEMF exposure from the experiments for 24 days. Then these animals were once again placed in the experimental chamber, and their conditioned reactions developed prior to MEMF exposure were analyzed.

Ten rats in the control group not subjected to the MEMF were also excluded from the experiments for 24 days after completion of their training. This time interval was not chosen randomly. Restoration of previously developed conditioned reactions after MEMF exposure occurs 20-25 days later (13,19). Normalization of the basic changes in human psychoneurology after cessation of contact with MEMF sources is observed in this same time interval (18).

Comparison of data acquired on animals in the control and experimental groups showed that disturbances in behavior noted in response to the MEMF have a functional, reversible nature, and the acquired habits are restored in the time interval indicated above practically without additional training.

Thus the experiments show that when subjected to MEMF for a long period of time, rats display a certain sequence of selective changes in the central architecture of goal-oriented behavioral reactions of different biological quality. Avoidance reactions suffer first of all, dynamic disturbances occurring in the mechanism behind assessment and synthesis of afferentations differing in biological quality.

In response to short-term MEMF exposure, assessment of the significance of situational afferentation in relation to avoidance is disturbed first of all. After longer exposure the conditioned stimulus loses its triggering action. Certain motor components of integral feeding and avoidance reactions disappear last of all.

As we had noted above, in response to an MEMF the animals made numerous persistent attempts to approach the feeder in response to the conditioned stimulus in the avoidance situation, despite intense electrocutaneous stimulation. This fact permitted the hypothesis that behavioral disturbances in response to short-term MEMF exposure are not only the product of disturbance of pretriggering integration; the capability of the animals to predict the result of their action and to correct an incorrect behavioral act suffers significantly as well.

Peculiarities of Extinction of a Conditioned Feeding Reaction in Rats Exposed to an MEMF

Many scientists (14,20,24) point to the inhibitory action of an EMF upon various aspects of the behavioral and, especially, conditioned reflex activity of animals. At the same time the nature of the inhibitory influence of an EMF remains unrevealed in many respects. A significant amount of experimental data have appeared in recent years which clearly do not fall in line with the notion that an EMF has inhibitory action (12,19,25,26).

If an MEMF does elicit inhibition in the central nervous system (CNS), then the question as to the sort of influence an MEMF has on development of internal inhibition of conditioned reactions is fundamental.

In this connection, in G. D. Antimoniy's experiments (5) we analyzed the action of an MEMF upon development of extinctional inhibition of the conditioned feeding reaction. The experiments were conducted on 30 rats which had been initially starved for 24 hours prior to the experiment. A conditioned feeding reaction was developed in all experimental animals in the chamber described in the first section of this article. In this reaction, in response to each light flash the animals rushed toward the feeder and ate the food presented to them when the rear wall of the chamber was white.

After the conditioned feeding reaction was developed, the rats were divided into two groups (experimental and control) containing 15 animals each. Both groups of animals underwent extinction of the conditioned feeding reaction. Extinction was performed in the presence of an MEMF for rats in the experimental group. Absence of a motor reaction toward the feeder in response to presentation of the conditioned stimulus served as the criterion of conditioned reaction extinction.

The experiments showed that exposure to the MEMF significantly hindered development of extinctional inhibition in the rats (Figure 1).

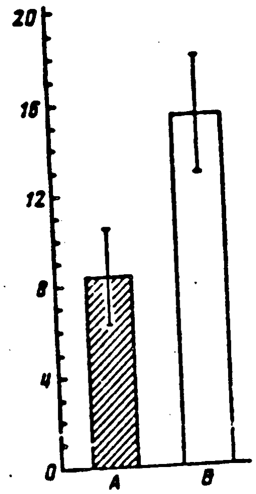

Figure 1. Mean Number of Failures to Reinforce a Conditioned Stimulus With Food, Necessary for Complete Extinction of the Conditioned Feeding Reaction in Rats: *A*--Control group; *B*--for animals during exposure to the MEMF; vertical axis shows the number of failures of conditioned stimulus reinforcement.

Among five animals in the control group, five to eight failures to reinforce the conditioned stimulus with food elicited extinction of the conditioned reaction. Eight rats required 8-10 nonreinforcements, while only two animals needed over 10 nonreinforcements.

Six rats in the experimental group, which experienced extinction in the presence of an MEMF, needed 12-15 nonreinforcements, seven animals needed 15-20 nonreinforcements, and two rats needed 20 nonreinforcements of the conditioned stimulus with food.

The average number of nonreinforcements of the conditioned stimuls with food necessary for extinction of the conditioned feeding reaction increased by almost two times among rats subjected to extinction in the presence of an MEMF as compared to the control group of animals. Thus development of conditioned extinctional inhibition worsens significantly in the presence of an MEMF. Similar observations were made by other authors (6,10), who noted that an MEMF dramatically hinders alteration of previously developed conditioned reflexes.

We should note that failure to reinforce conditioned stimuli as a rule elicited emotional reactions expressed to varying degrees--from orientational exploratory to aggressive--among control animals. These reactions were not clearly expressed among rats exposed to the MEMF, and the reactions never had an aggressive coloration.

According to P. K. Anokhin's functional system theory (2), the biologically negative reaction arising upon failure to reinforce a conditioned feeding reflex due to inconsistency between the real result and the properties of the programmed apparatus of the action result acceptor is the principal cause leading to development of internal inhibition. From this standpoint the delay in development of extinctional inhibition of the conditioned feeding reaction in rats during the time of exposure to an MEMF may be dependent chiefly upon selective suppression of a biologically negative emotional reaction arising in response to nonreinforcement of the conditioned reflex. It can be believed that absence of a negative emotional reaction when conditioned feeding stimuli are not reinforced in the presence of an MEMF is what leads to the arisal of a large number of reactions to nonreinforced conditioned stimuli. On the other hand, according to P. K. Anokhin's ideas, internal inhibition occurring during extinction of conditioned feeding reactions is associated with formation of a new acceptor of the result of action in response to nonreinforcement in animals. It may be possible that formation of this apparatus in the presence of an MEMF is encumbered when the negative emotional reaction is suppressed.

Peculiarities in Extinction of Conditioned Reactions of Two Communicating Animals in the Presence of an MEMF

The capability for assessing a situation reveals itself especially distinctly when several animals interact (11), and chiefly in cases where individuals with the same dominant motives interact.

In this connection the research of our colleague, A. V. Masterov (16) had the task of revealing the way an MEMF influences extinction of conditioned feeding and avoidance reactions of two interacting rats. The research was conducted on rats subjected to 1 to 2 days of starvation.

The idea behind the experiments in this series was to determine changes in the goal-oriented conditioned reflex activity of the animals in conditions where one of the trained animals is subjected to extinction of its conditioned feeding reaction in isolation, after which another animal, also trained in these conditions, is added to its cage.

Control experiments were first performed with 10 pairs of rats (18 males, two females). A conditioned feeding reaction to a light stimulus was developed in each of the two rats separately using the procedure described above. After the conditioned feeding reaction was developed, in response to a light flash the animals rushed toward the feeder on the left wall of

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the chamber and ate the food presented to them after 5 seconds. Then one of the rats was subjected to extinction of the developed conditioned feeding reaction. After this another rat was placed in the chamber with it. After being allowed to communicate for 30-40 minutes, the planted rat was subjected to extinction of its conditioned feeding reaction in the presence of the first, main rat.

The experiments showed that in the presence of main rats which had been subjected to extinction of the feeding reaction previously, all planted rats exhibited faster extinction of the conditioned feeding reaction. At the same time, in the presence of planted animals all of the main rats first exhibited restoration of conditioned feeding reactions in response to the conditioned signal, and it was only after one or two nonreinforcements that repeated extinction of these reactions was observed (Figure 2*A*). All of this points to distinct mutual influence between the rats during extinction of conditioned feeding reactions.

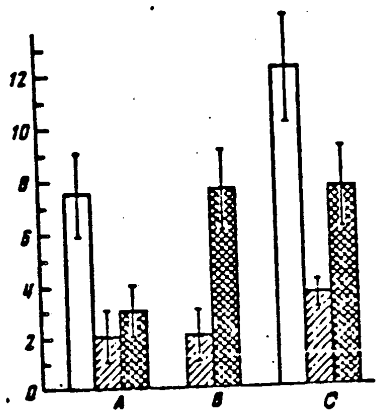

Figure 2. Mean Number of Failures to Reinforce a Conditioned Stimulus With Food Necessary for Complete Extinction of a Conditioned Feeding Reaction in Communicating Rats: *A*--Before; *B*--during exposure to the MEMF, with the main rat subjected to extinction of the conditioned reaction beforehand; *C*--rats in the main group were exposed to the MEMF beforehand. Light column--number of nonreinforcements for main rats in the absence of planted rats; striped column--the same, in the presence of planted rats; cross-hatched column--number of nonreinforcements for planted rats in the presence of main rats; vertical axis--number of nonreinforcements of the conditioned stimulus.

After revealing the background laws governing extinction of conditioned feeding reactions of two interacting animals in the next series of experiments conducted on 10 other pairs of rats (16 males, four females), we analyzed the peculiarities of the extinction of conditioned feeding reactions in rats developed beforehand as they interacted in an MEMF.

The experiments showed that as compared to control experiments, on the background of exposure to an MEMF all animals planted a second time exhibited an increase in the number of nonreinforcements required for complete extinction of the conditioned feeding reaction in the presence of the main rats. While in control experiments the number of nonreinforcements was two to four, after exposure to the electromagnetic field it increased to 6-9 (Figure 2*B*). As in the control experiments, main rats subjected to the MEMF recovered their conditioned feeding reactions in the presence of planted rats. The number of nonreinforcements required to extinguish this reaction remained the same as in the control experiments--that is, one to three.

These experiments thus indicate that in the presence of an MEMF the usual interaction between two animals is disturbed in the process of developing conditioned inhibition of feeding reactions. Planted animals cease to react to animals in the main group, while the MEMF has no pronounced influence upon the latter.

We revealed from a special series of experiments the way two rats interact after preliminary extinction of the conditioned feeding reaction of the main rats in an MEMF. The essence of this series of experiments was to determine whether or not the main rats would exhibit ordinary behavior in the presence of planted rats after preliminary exposure to an MEMF. The experiments were conducted with five pairs of experimental rats (nine males, one female). The experiments showed the following. As in experiments conducted by G. D. Antimoniy (4), after extinction of the conditioned feeding reaction the number of nonreinforcements required by main rats increased from 6-9 to 10-14. After this other rats with previously developed conditioned feeding reactions were planted together with the main rats. It was found that in response to the conditioned light stimulus the number of nonreinforced food-getting reactions required by the main rats increased. The same was observed for planted rats as well (Figure 2*C*).

Experiments in this series thus show that preliminary extinction of conditioned feeding reactions in the presence of an MEMF also disturbs interaction between two animals.

And so, the experiments we conducted showed that an MEMF has a noticeable effect upon the mutual influences of two rats after conditioned feeding reactions are extinguished. This effect is exhibited both when the rats are subjected to an MEMF during interaction and prior to interaction.

Peculiarities in the Change in Reinforcement Side Choice Reactions in a T-Maze Under the Influence of an MEMF

Experiments in this series were conducted by our colleagues, G. D. Antimoniy and G. K. Vasina on rats with a special T-maze designed by D. S. Nadezhdinyy (17).

The rats, which had first been deprived of water for 24 hours, were placed in the start compartment of the maze, the exit from which was blocked by a curtain. Lamps were located on both sides of the start compartment. Turning one on meant that the animal could obtain water from either the right or left feeder of the T-maze. Next to each feeder there was a safety curtain which was opened only if the animal made the right choice in response to the stimulus indicating the side of reinforcement. The animals were able to return to the start compartment after both right and wrong choice of the side of reinforcement.

The animals were exposed to the MEMF in the start compartment by means of capacitor plates connected to the generator; the MEMF was turned on simultaneously with the signal lamp, and it was turned off after the animal exited to the central corridor.

The time required by the animal to pass through the maze was recorded by photoelectric cells. Only preliminarily trained animals, for which wrong reinforcement side choice reactions were completely absent in the course of two or three experimental days and for which the latent time and total reaction time were stable, were subjected to the MEMF.

The experiments were conducted with 18 rats. It was demonstrated that the MEMF elicited errors in reinforcement side choice at an average level of 18 percent in 15 rats on the day of exposure. On the second and third days after exposure to the MEMF the rats exhibited a decline in the total number of wrong reactions averaging up to 11 percent. Later, the number of wrong reactions grew to an average of 15 percent. On subsequent experimental days the number of wrong reactions made by the rats decreased continuously, and by the 8th day all animals had, for practical purposes, completely recovered their capability for choosing the side of reinforcement (Figure 3). In the first days after exposure to the MEMF we observed additional disturbances in the developed behavior as follows. As a rule, after water reinforcement the rats remained at the feeder and would not return to the start compartment for a long period of time. The time the animals remained in the start compartment before exiting increased, and the total number of runs to the feeders decreased.

Thus the experiments in this series also distinctly demonstrated that an MEMF significantly disturbs afferent synthesis and formulation of the goal for action--the acceptor of the result of action--in the animals. Quite typically, these disturbances are manifested in the animals only for a particular period of time after one-time exposure, and they are subsequently compensated. Other authors also indicate that animals have a capability for adapting to the action of MEMF of various parameters (9,23).

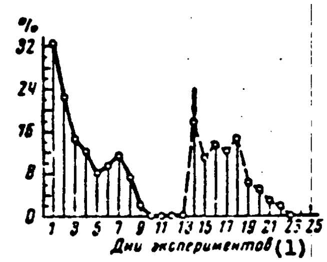

Figure 3. Graphical Characteristics of Rat Behavior in a T-Maze Before, During, and After Exposure to an MEMF: Abscissa--experimental days; ordinate--percent wrong reactions with respect to total number of presentations of conditioned stimuli in the experimental day; the arrow indicates the day of exposure to the MEMF. Averaged for 18 animals.

Key:

1. Experimental days

Dynamics of the Disturbance of the Self-Stimulation Reaction in Rats in the Presence of an MEMF

The results of experiments described in the previous sections show that in all cases an MEMF has a selective action upon the capability of animals to adequately assess a situation, on the action of triggering stimuli and reinforcement and so on. In P. K. Anokhin's opinion (2) this apparatus for assessing the results of behavior depends to a significant degree on emotional states taking an active part in the structure of the acceptor of the results of action.

Research by Yu. A. Makarenko (15) showed that the mechanism behind the emotional component of the acceptor of the result of action manifests itself clearly in the self-stimulation reaction: Application of current stimulating cerebral structures immediately leads to an inconsistent reaction--an increase in the frequency with which the stimulus lever is pressed.

We analyzed the dynamics behind the self-stimulation reaction in rats exposed to MEMF characterized by different modulation frequencies in order to reveal the possible action of the MEMF upon the emotional reactions of the animals.

The experiments were conducted with 30 rats of both sexes using electrodes chronically implanted in various subcortical formations--the anterior, latera and posterior hypothalamus, and the mesial and lateral septal nuclei. Stimulation of these brain structures by electric current elicited a self-stimulation reaction in all animals when the current parameters were 10-12 volts, 55 Hz, pulse duration 0.1-0.5 msec, and pulse train duration 0.3-0.6 se

We studied the self-stimulation reaction of these animals in a special chamber in which a 39 MHz MEMF, modulated at 2, 7, and 50 Hz, was created between two plates located on the side walls. Exposure time was 10 minutes in all experiments.

The experiments showed the following (Figure 4).

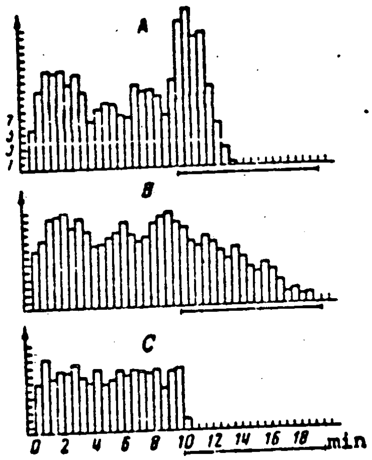

Figure 4. Dynamics Behind Change in the Self-Stimulation Frequency of Rats Exposed to EMF Modulated at Different Frequencies: *A*--Modulation frequency 2 Hz, *B*--7 Hz, and *C*--50 Hz. Each column represents the number of times the pedal was pressed in a 30-second interval, averaged for 10 animals. The lines below the graphs indicate time of exposure to the MEMF.

An increase in the frequency of self-stimulation reactions to 93 percent was observed in the first two minutes of exposure to an MEMF with a modulation frequency of 2 Hz; then the frequency of self-stimulation reactions declined sharply, disappearing entirely after 4 minutes. When the rest were exposed to an MEMF with a modulation frequency of 7 Hz, the self-stimulation reaction hardly differed from the background reaction in the first 2 minutes; only after this time was a reduction in its frequency observed, continuing for 12-15 minutes.

A different pattern was observed in the presence of an MEMF with a modulation frequency of 50 Hz, which blocked the self-stimulation reaction practically immediately in all animals. Typically, these effects of the MEMF did not depend on the locations of the tips of the stimulating electrodes.

Thus these experiments clearly showed that an MEMF having a modulation frequency of 50 Hz has the most highly pronounced blocking influence upon emotional reactions of the animals. The experimental data we acquired indicate a fundamental possibility for directed influence upon the emotional reactions of animals by an MEMF: the MEMF activates these reactions when its modulation frequency is 2 Hz and blocks them when it is 50 Hz.

Considering that an MEMF with a modulation frequency of 50 Hz blocks not only positive but also, as we had noted above, negative emotional reactions, it can be believed that initial disturbance of the emotional apparatus lies at the basis of the changes experienced in the goal-oriented behavior of animals exposed to an MEMF.

And so, the experiments we conducted indicate clear selective action of an MEMF having a modulation frequency of 50 Hz upon certain key mechanisms in the central architecture of behavioral functional systems in animals directed at satisfying biological needs.

The mechanisms experiencing the greatest disturbance include those of the animal's assessment of the action of situational and triggering stimuli and of surrounding individuals of the same species and, on this basis, the mechanisms behind decision making and prediction of future results--the apparatus of the acceptor of action results. All of this is accompanied by significant disturbances in emotional reactions.

It can be believed that the disturbances we have noted in goal-oriented activity of animals exposed to an MEMF are associated chiefly with selective disturbance of emotional apparatus, that unique emotional component of goal-oriented activity which our research revealed in man (22). This is also indicated by previous works which showed the selective action of MEMF upon limbic structures of the brain (21). Stimulation of the limbic structures of the brain in turn blocks the reticular formation of the midbrain and reverse afferentation passing to cortical cells from the environment.

Comparing the results of our MEMF experiment with research on the action of psychopharmacological agents of different series (8), we can note almost complete similarity in the spectrums of their action upon emotional reactions and the states of animals.

We should note that animals have a capability for adapting to the action of an MEMF. The mechanisms lying behind such adaptation are still not clear. This question will be the object of research we will conduct in the future.

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