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BIOMEDICAL AND BEHAVIORAL SCIENCES

(GUO 38/77)

EFFECTS OF NONIONIZING ELECTROMAGNETIC RADIATION

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EFFECTS OF NONIONIZING ELECTROMAGNETIC RADIATION

CONTENTS PAGE

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

Moscow ZHURNAL VYSSHEY NERVNOY DEYATEL'NOSTI in Russian No 5, 1976 pp 899-909

[Article by K. V. Sudakov, Scientific Research Institute of Normal Physiology 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. Sechenov]

[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 special role belongs to modulated electromagnetic fields in the radio-frequency range (12-14,18-20,23-26).

The systems approach, functional system theory in particular, has been found 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 situations:

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).

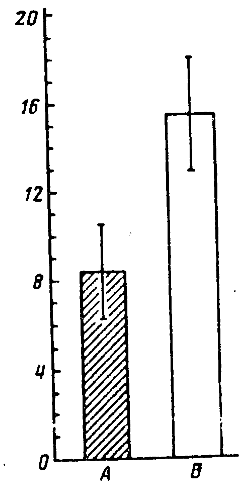

Figure 1. Mean Number of Failures to Reinforce a Conditioned Stimulus With Food, Necessary for Complete Extinction of the Conditioned Feeding Reaction in Rats: *A*--Control group; *B*--for animals during exposure to the MEMF; vertical axis shows the number of failures of conditioned stimulus reinforcement.

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 stimulus 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 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.

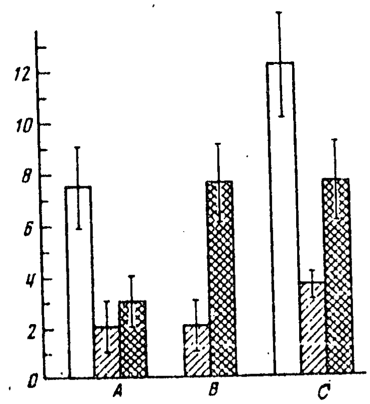

Figure 2. Mean Number of Failures to Reinforce a Conditioned Stimulus With Food Necessary for Complete Extinction of a Conditioned Feeding Reaction in Communicating Rats: *A*--Before; *B*--during exposure to the MEMF, with the main rat subjected to extinction of the conditioned reaction beforehand; *C*--rats 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).

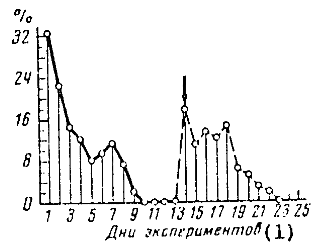

Figure 3. Graphical Characteristics of Rat Behavior in a T-Maze Before, During, and After Exposure to an MEMF: Abscissa--experimental days; ordinate--percent wrong reactions with respect to total number of presentations of conditioned stimuli in the experimental day; the arrow indicates the day of exposure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

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).

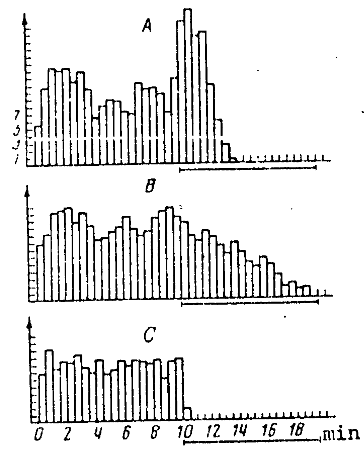

Figure 4. Dynamics Behind Change in the Self-Stimulation Frequency of Rats Exposed to EMF Modulated at Different Frequencies: *A*--Modulation frequency 2 Hz, *B*--7 Hz, and *C*--50 Hz. Each column represents the number of times the pedal was pressed in a 30-second interval, averaged for 10 animals. The 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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SELECTIVE ACTION OF DECIMETER WAVES ON CENTRAL STRUCTURES OF THE BRAIN

Leningrad FIZIOLOGICHESKIY ZHURNAL SSSR in Russian Vol 63, No 5,May 77 signed to press 17 Jan 75 pp 668-672

(Article by V. R. Faytel'berg-Blank, and G. M. Perevalov, Department of Pathological Physiology and Biophysics, Agricultural Institute, Odessa)

(Text) The dynamics of commisural activity of single neurons was studied to clarify the sensitivity of a number of central structures of the brain to the action of electromagnetic fields of decimeter waves (EMF DW). It has been shown that greatest reactivity to EMF DW is displayed by neurons of the hippocampus and hypothalamus, with a stimulated type of reaction. The predominating type of reaction, for neurons of the reticular formation of the midbrain and of specific nuclei of the thalamus, is inhibitory. The number of neurons which actively respond to the action of EMF DW, or which are unreactive, varies depending on the power density of the electromagnetic field.

Irradiation of biological specimens with electromagnetic fields (EMF) leads to manifestation and development of a combination of morpho-functional shifts, at the basis of which are specific and non-specific reactions/8,14-21, and others/. According to findings of a number of authors /10,20-23/, EMF can exert an immediate action upon brain tissue. Some structures (the cortex of the large hemispheres and hypothalamus) have been identified as the most sensitive to the action of EMF of different physical characteristics. Other investigators consider the reticular formation /27/ and the hippocampus /2-5/ as the most reactive formations of the brain. One of the possible causes of the contradictory character of these conclusions could be the use, for animal irradiation, of EMFs which are significantly different in power density.

An analytical approach to study of the selective action of EMF on structures of the brain involves the need to evaluate the character of the reaction of individual neurons to the stimulus presented. Comparison of the data of analysis of neuronal activity with results of an evaluation of the activity of cerebral structures based on integrative indices can give the fullest information about participation of some or other neural formations in responses to electromagnetic radiation.

The task of the present report, proceeding from what has been said, was to study the character of the reactions of a number of central structures of the brain during the action on the body of EMF of the decimeter range.

PROCEDURE

In experiments on 25 chinchilla rabbits, 2.5 kg in weight, an investigation was made of commissural activity of 193 neurons of different formations of the brain (dorsal hippocampus, specific and non-specific nuclei of the thalamus, hypothalamus, and reticular formation of the midbrain). To record the peak potentials of the neurons, glass micropipettes (diameter of the tip 0.2-2 mc) were employed, filled with 2.5 M solution of KCl. Microelectrodes were introduced into the rabbit brain by the method of Konstantinov, et al. /9/. Stereotaxic coordinates of the subcortical structures were determined based on an atlas of the rabbit brain /28/. Control of positioning the active tip of the microelectrode in the cerebral structures being examined was carried out morphologically after completion of a series of trials on an animal. The commissural activity was recorded on a device consisting of a cathode follower, an intensifier of the biopotentials, and a loop oscillograph. Simultaneously, measurements were carried out of the duration of the intercommissural intervals on an electron-counter frequency meter CHZ-24. The basic statistical characteristics of the sequence of the commissures /13/ were obtained with processing of the data on the "Minsk-22" computer. The animals were irradiated with the help of the "Volna-2" physiotherapy apparatus which generates electromagnetic oscillations of the decimeter range of frequency 460 mHz. In the experiments, study was made of the action of electromagnetic radiation with a power flux density (PD) of 2 and 5 mw/cm^2. The PD was measured with the PZ-9 instrument. At the time of irradiation of an animal, the vibrator of the elongated radiator of the generator was oriented along the axial line of the body. The head of the rabbit was exposed to the EMF action. For protection of the other parts of the body, from electromagnetic radiation, a special covering was used, made according to the principle of quarter-wave matching (a briquet of layers of radio-absorbing and thermally-insulating material of $\lambda/4$ thickness and of brass mesh). The coefficient of reflection of incident energy of such a covering is less than 1%. Tests were conducted on animals in the following way: 5-minute recording of background activity of the neuron; 10-minute radiation; 5-minute recording of the activity of the neuron after the EMF action. After 24 hrs the experiment was repeated in the same sequence, recording the activity of a neuron located at a distance of 0.2-0.5 mm from the preceding one. In the course of 7 days the animal was exposed to seven-fold action of electromagnetic radiation of definite intensity. In control experiments, recording of the activity of the neurons was done under analogous conditions except for the irradiation of the animal.

EXPERIMENTAL RESULTS

The character of the response of neurons of the brain to EMF DW was non-uniform, and so we separated all the recorded neurons by type of response into 3 groups. The first group consisted of neurons, the frequency of the commissures of which was increased, statistically reliably, after the action of EMF (a stimulated type of reaction). The second group had neurons with reliably decreasing frequency of the commissures after the irradiation (an inhibited type of reaction). Neurons which didn't change, reliably, the frequency of commissures made up the third group. After irradiation of the

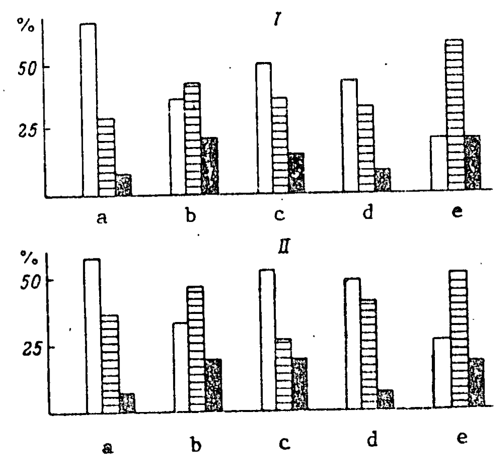

Figure 1. Intensity of reaction of neurons of central structures of the brain to EMF DW 2 (I) and 5 (II) mw/cm^2

a--dorsal hippocampus; b--specific nucleus of the thalamus; c--non-specific nucleus of the thalamus; d--hypothalamus; e--reticular formation of the midbrain; First column--stimulated neurons; Second--inhibited; Third--non-reactive to EMF. Ordinate--number of neurons in % of total number of those examined in a definite brain formation.

animal brain with EMF DW 2 mw/cm^2 an increase was seen in the frequency of discharges in 45.6% of the brain neurons examined, 39.7% lowered the frequency of the commissures, 14.7% did not change their activity. In the control experiments only 2% of the neurons altered their activity expressed in an increase of discharges, 4.0% lowered the frequency of the commissures. The distribution of the nervous cells which reacted to the EMF 2 mw/cm^2, and the non-active,was different in the examined structures of the brain. The largest quantity of stimulated neurons was determined (Fig. 1) in the dorsal hippocampus (64.3 of the total number recorded in this formation). Decrease in activity of intercommissural intervals of neurons of the dorsal hippocampus was seen in the 3 min period after the action of the irradiation (Fig. 2). In the hypothalamus, the number of neural cells with a stimulated

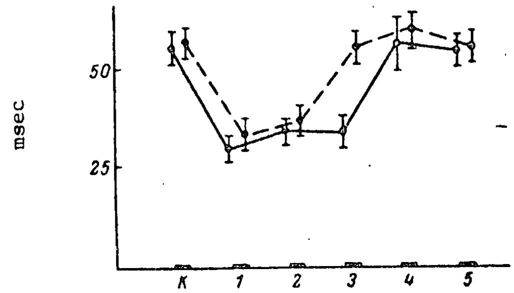

Fig. 2. Change of duration of intercommissural intervals of 14 neurons of the dorsal hippocampus after the action of EMF DW
Abscissa: K--control data before irradiation; figures--time, in min, after irradiation
Ordinate--mean intercommissural interval. Solid line--PD 2 mw/cm^2, broken line--5 mw/cm^2

type of reaction to EMF amounted to 58.3%. The period of restoration of commissural activity of neurons of the ventromedial nucleus of the hypothalamus to the initial level lasted 2 min (Fig. 3). The number of neural cells with an inhibited type of reaction to the EMF dominated in the nuclei of the thalamus and reticular formation of the midbrain. Characteristic of the central thalamic nucleus was a rapid restoration of commissural activity to the initial level after the action of the field, and an expressed asymmetry in the area of the large intervals (see Table). Part of the neurons of the brain did not react to EMF 2 mw/cm^2. Note must be taken of a definite dependence of the character of the neuronal responses on the initial background frequency of discharges. The mean value of the frequency of the commissures of the stimulated neurons in the majority of cases was somewhat lower than this value for neural cells with an inhibited type of reaction to EMF. A similar dependence was noted by several investigators /6,25/ in study of the response of neurons of the cortex of the large hemispheres to light and sound.

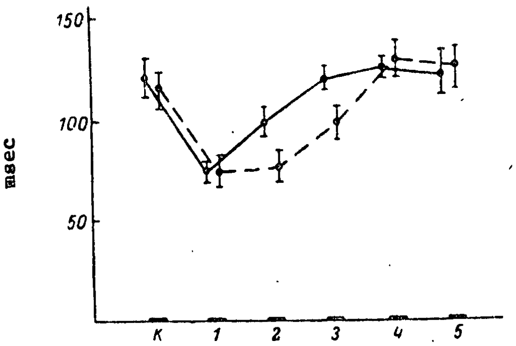

Fig. 3. Change of duration of intercommissural intervals of 14 neurons of the ventromedial nucleus of the hypothalamus after the action of EMF DW
Abscissa: K--control data before irradiation; figure--time, in min, after irradiation
Ordinate--mean intercommissural interval. Solid line--PD 2 mw/cm^2; broken line--5 mw/cm^2

1. Показатели	2. Фоновая актив-ность	3. После воздействия ЭМП 2 мВт/ см² (в мин.)				
		1	2	3	4	5
Средний интервал (мсек.)	119.10	67.33	120.33	116.67	108.83	126.00
Стандартное отклонение	9.18	4.16	4.55	9.97	3.82	6.81
Коэффициент асимметрии	0.35	0.28	0.41	0.43	0.51	0.57
Коэффициент эксцесса	0.19	0.23	0.36	0.25	0.39	0.46

Key to table: Statistical indices of the sequence of the commissures of 14 neurons of the central thalamic nucleus.

1. Indices
   - average interval
   - standard deviation
   - coefficient of asymmetry
   - coefficient of excess
2. Background activity
3. After action of EMF 2 mw/cm^2 (in min)

After the action on the animal's head of EMF 5 mw/cm^2 a rise was seen in frequency of discharges in 43.8% of the neurons, 41.1% decreased the

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commissural frequency; 15.1% did not react to the irradiation. The number of stimulated neurons in the hippocampus decreased by 7.2% and in the hypothalamus by 8.3% (Fig. 1). Along with this, an increase was seen in the number of neurons responding with inhibition to the action of EMF 5 mw/cm^2. In the hippocampus, the number of neural cells with an inhibited type of response was 35.7%, in the hypothalamus 42.9%. These same structures of the brain displayed the lowest number of neurons which did not react to the EMF. The dynamics of the pulse activity of the neurons of the dorsal hippocampus were characterized by a shorter period of after-effect than in the case of irradiation of animals with EMF 2 mw/cm^2 (Fig. 2). In the neural cells of the hypothalamus, the period of restoration of commissural activity to the initial level, conversely, was increased by a factor of 1.5 (Fig. 3).

DISCUSSION OF RESULTS

The studies we have presented indicate that the effect of EMF DW of various intensity on the brain of rabbits evokes changes, in various directions, in the activity of neurons of the central structures. A similar character of response of the neurons was noted by several investigators /7,11,12/ during use of other physical factors (light, sound, constant magnetic field). Analysis of the commissural activity of neurons indicates that EMF DW exerts a selective action on central structures of the brain. The largest number of neurons which actively respond to the action of this physical factor was observed in the hippocampus, the least in the reticular formation of the midbrain. The high sensitivity of the hippocampus to the action of factors of an electrical nature was noted by a number of authors /1-5/, under other experimental conditions. Thus, selective stimulation of limbic structures of the brain (primarily,the hippocampus) was seen during the action of an electric current under conditions of electronarcosis /1/. Short-term irradiation of animals with EMF with a frequency of 39 mHz evoked the manifestation of isolated convulsive activity in the hippocampus /2,4/. Increase in duration of the action led to dissemination of this activity to other limbic structures and to the brain cortex. Lyuk'yanova /12/ found that, under the action of a constant magnetic field, the number of inhibited neurons somewhat exceeds the number of stimulated neurons in all formations of the brain, except the hippocampus. The high sensitivity of the hippocampus can be explained by its known cytoarchitectonic and electrophysiological features /26/. The data obtained by us on the high reactivity of the hypothalamus to EMF DW agree with the results of work of a number of authors /18,20-23/ who--on the basis of analysis of the summary bioelectrical activity of the neural formations under the action of EMF--have relegated the hypothalamus to the number of more sensitive structures of the brain. The varied direction of responses of the neurons of the reticular formation of the midbrain and of the non-specific nuclei of the thalamus to EMF can testify to the weakening of the inhibiting effect of the cortex of the large hemispheres upon the subcortical structures.

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HYPNOGENIC EFFECTS OF A MODULATED ELECTROMAGNETIC FIELD

Moscow BYULLETEN' EKSPERIMENTAL'NOY BIOLOGII I MEDITSINY in Russian No 8, 1977 pp 146-149

[Article by K. V. Sudakov, corresponding member of the USSR Academy of Medical Sciences, and G. D. Antimoniy, Laboratory of Emotions and Emotional Stress (headed by K. V. Sudakov, corresponding member of the USSR Academy of Medical Sciences), Scientific Research Institute of Normal Physiology imeni P. K. Anokhin, USSR Academy of Medical Sciences, Moscow, submitted 6 Dec 76]

[Text] A study was made of the dynamics of behavioral and EEG changes in rats during prolonged exposure to a modulated electromagnetic field (40 MHz frequency, 50 Hz modulation frequency, 100-120 V/m field voltage). It was found that exposure to a modulated electromagnetic field leads to appearance of phasic disturbances of conditioned alimentary and defense reactions, to the extent of a cataleptic state. These behavioral disturbances are due to a change in normal corticosubcortical correlations.

Key words: Modulated magnetic field, hypnogenic effects; epileptiform activity; catalepsy.

In the course of our study of the effects of modulated electromagnetic fields (MEMF) on animal behavior [1-3], we observed that some animals presented a state resembling catalepsy with exposure of a specific duration or intensity. The authors of a number of studies [4-7] also observed changes in behavioral reactions of animals under the prolonged effect of various electromagnetic fields (EMF), that bore a resemblance, in many respects. to the hypnotic phases described in the laboratory of I. P. Pavlov. Clinicians have also noted development of states of the cataleptic and narcoleptic types in humans who sustained particularly severe EMF lesions [8].

In order to investigate the hypnogenic effects of MEMF, we examined the dynamics of changes in behavioral reactions of rats and compared them to the changes in electric activity of the cortex and subcortical structures of the brain related to exposure to MEMF for various periods of time.

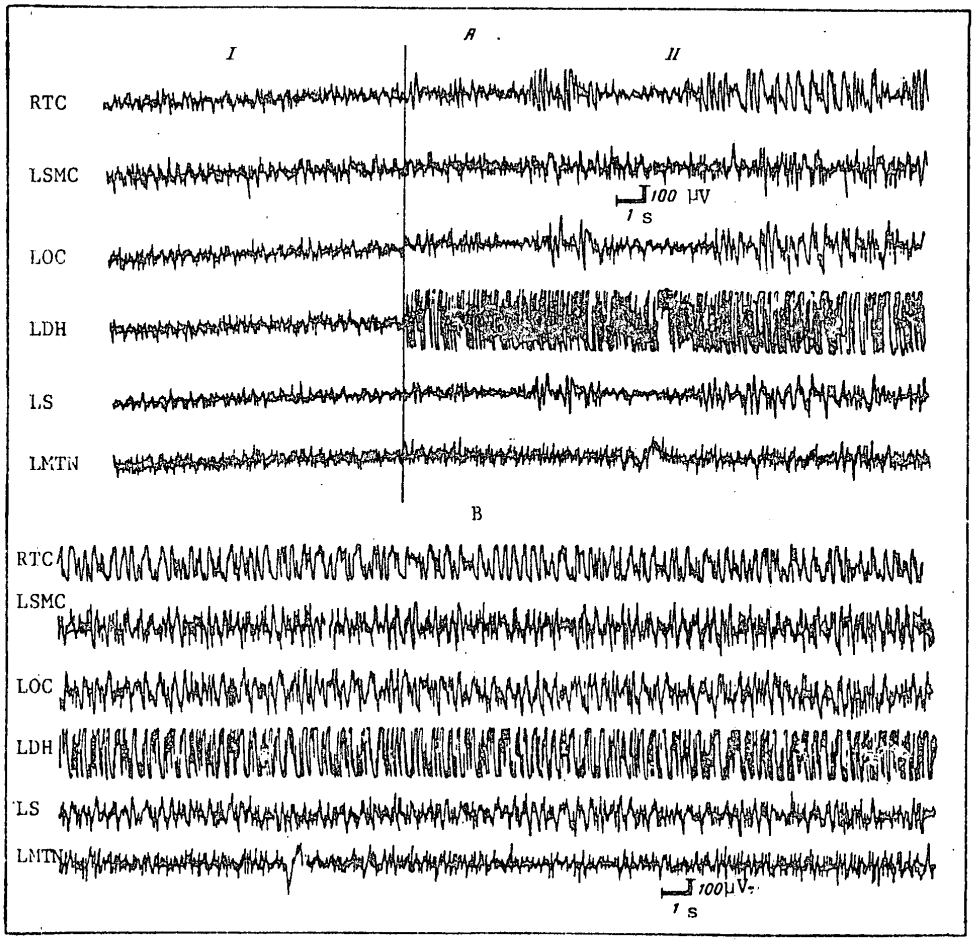

Figure 1. Changes in bioelectric activity of the rat brain at different stages of prolonged exposure to MEMF

A) first phase
B) second
C) third
D) fourth (explained in the text)
I) background bioelectric activity
II) bioelectric activity after 15-min exposure to MEMF

RTC) right temporal cortex
LSMC) left sensorimotor cortex
LOC) left occipital cortex
LDH) left dorsal hippocampus
LS) left septum
LMTN) left medial thalamic nucleus

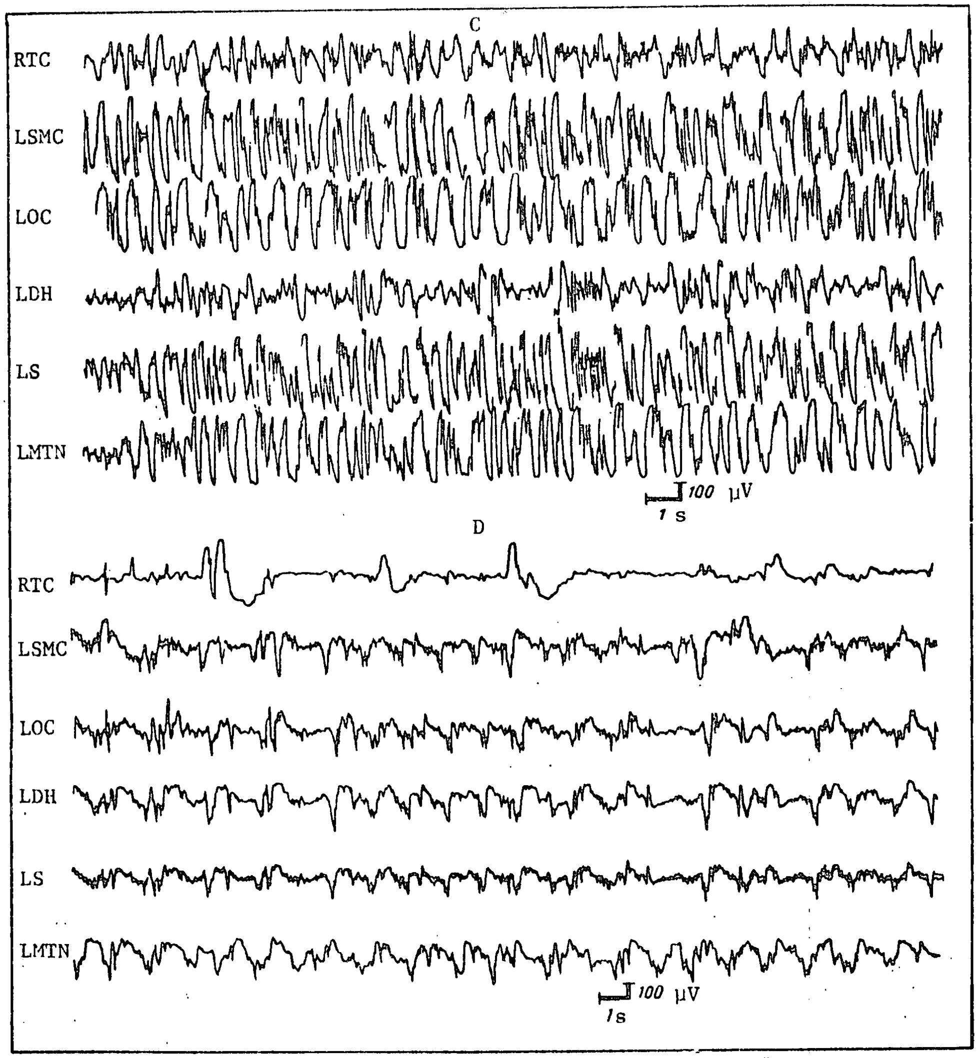

Figure 1. [continued]

Methods

Experiments were conducted on 76 noninbred albino rats of both sexes. We first developed alimentary and defense reactions to the same photic stimulus, but with different colored back wall of a special chamber. The developed conditioned alimentary reaction was characterized by the fact that, in the case of a white back wall in the chamber, the animals ran to the feeder on the left wall of the chamber. The developed defense reaction was characterized by the fact that, with a black back wall in the chamber, the animals hid in the right part of the chamber in response to the conditioned stimulus since, in this case, electric current was delivered to the floor in the left part of the chamber, in front of the feeder. We recorded electric activity of the cortex and several subcortical structures. We studied the developed conditioned reactions with exposure to MEMF (40 MHz frequency, 50 Hz modulation frequency, 80-100% depth of modulation, 100-120 V/m force, exposure for 2 min to 2.5 h), which was created by a generator in the chamber, by means of condenser plates attached along the walls.

In a series of experiments, we exposed groups of rats, each consisting of 6-8 animals, to the same MEMF.

Results

The experiments revealed that the animals presented four disctinct phases of impairment of developed conditioned alimentary and defense reactions in the course of prolonged exposure to MEMF (see Table). The first phase was seen in 54% of the animals. It was characterized by appearance of local epileptiform activity in the dorsal hippocampus (see Figure 1A); the second phase was observed in 75% of the experimental animals. In this phase, epileptiform activity was recorded in the hippocampus, hypothalamus, septum, amygdala, as well as temporal and occipital cortex (see Figure 1B). The third phase was observed in 86% of the animals tested. Here, epileptiform activity extended to all of the brain structures examined (see Figure 1C). The fourth phase (see Figure 1D) was characterized by the appearance of generalized slow (1-2 Hz), sharp-wave oscillations with an amplitude of 150-200 V or EEG depression. This stage was observed in 35% of the animals. And 5% of the rats developed genuine catalepsy with signs of "wax-like flexibility."

Changes in behavior analogous to those described above were observed under the influence of MEMF in the groups of rats consisting of 6-8 animals each and in about the same functional condition after eating with unrestricted behavior in the chamber. We examined five such groups. During the first few minutes of exposure to MEMF there was an increase in general motor activity of the animals. By the end of the 1st hour, there was depression of motor activity, which progressed in the course of exposure to MEMF. After the 1st hour of exposure, the rats became virtually "tame," and did not react to harsh sounds, stroking, etc. After exposure for 1.5-2 h, there was profound depression of motor activity in virtually all of the animals. The rats stopped reacting not only to sensory but biological stimuli, for example, to placing a rabbit and even a cat in the experimental chamber. In these experiments, 5% of the animals developed a cataleptic state (Figure 2 [not reproduced]).

Selective phasic disturbances of developed conditioned reflex, purposeful defense and food-obtaining behavior in rats exposed to a modulated electromagnetic field for different periods of time

Phase	MEMF exposure	Defense behavior	Alimentary behavior
1st	5-20 min	Selective impairment of conditioned defense reactions; repeated movement in response to conditioned stimulus in direction of feeder in spite of nociceptive stimulus	Increased fluctuation of reaction time from start of conditioned stimulus to reinforcement
2d	20-45 min	Movements in direction of feeder in response to conditioned stimulus in spite of nociceptive stimulus	Longer reaction time from start of conditioned stimulus to reinforcement; appearance of defense reactions in "food" situation to conditioned stimulus and motor reactions to feeder that are not terminated by food intake
3d	45-60 min	No reactions to conditioned triggering stimulus	No reactions to conditioned triggering stimulus
4th	1.5-2.5 h	Profound depression of general motor activity; animals retain unnatural positions ("wax-like flexibility"); no behavioral or EEG reactions to direct nociceptive stimulation	No chewing and swallowing of food when placed in mouth

Thus, these experiments revealed that animals present phasic changes in behavioral reactions due to impairment of normal corticosubcortical correlations in the course of prolonged exposure to MEMF (50 Hz).

The phasic changes we demonstrated in behavior and bioelectric activity of the rat brain during exposure to MEMF resemble, in many respects, the hypnotic phases described in the laboratory of I. P. Pavlov. Thus, the first phase could be interpreted as the "paradoxical" phase, the second, as the "ultraparadoxical," the third, as the "inhibitory" and the fourth, as the "cataleptic." All this suggests that MEMF may have a hypnogenic effect.

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