
NON-IONIZING RADIATION

The Effect of Repeated Exposure to Complexly Organized Electromagnetic Radiation on the Rat Behavior in the “Open Field” Test

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Abstract—The effect of threefold (1 hour a day with an interval of three days) and multiple (8 weeks, 5 days a week, 2 hours a day) pulsed-modulated electromagnetic radiation on the orienting-exploratory response was studied on males and females of Wistar rats by the “open field” method. The animals were irradiated in an anechoic chamber in the zone of the formed wave of the microwave source (a block of 10 generators carrying frequencies from 1 to 4 GHz, the total pulse power density 300 $\mu\text{W}/\text{cm}^2$, pulse duration 25 ms, sweep cycles 1–6 Hz, cycle turn-around time 30 s). It was shown that the exposure to such parameters could cause a stress reaction and an impairment of long-term memory in some irradiated animals, female rats being more sensitive to the action of microwaves than males. This reaction was transient and the animal behavior was restored 1.5–2 months after cessation of irradiation. However, there is a danger that in the case of constant exposure to microwaves, which, for example, occurs in mobile users, such behavior deviations may be fixed and clinically significant.

Keywords: microwaves, open-field test, orienting-exploratory response, rats

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INTRODUCTION

In the modern world the human body is exposed to complex electromagnetic radiation (EMR) due to the introduction into all spheres of new sources of different powers, frequency ranges and modulation modes, which causes serious concern among the scientific community [1–5]. The central nervous system, the state of which can be assessed by a number of tests, is very sensitive to EMR effects [6].

One of such tests is the study of the orienting-exploratory response (OER) of animals in an “open field.” This method, despite its apparent simplicity, is quite informative and is often used by both domestic and foreign researchers when studying the effects of non-ionizing radiation. Studies in the 1970s–1990s showed that when exposed to microwaves in doses that caused an increase in the body temperature of animals by one degree their OER was disrupted [7]. At lower intensities of the influencing factor the results were not so clear. In particular, some authors did not find negative consequences of chronic exposure to EMR on the behavior of rats in an open field [8, 9]. At the same time, most researchers noted some negative effects [10–18].

Previously we studied the effects of low intensive, repetitive pulse-modulated EMR (within mobile phone ranges) in different modes of action on associative learning of rats using the conditioned avoidance response (CAR) test. It was found that such exposure could cause functional manifestations from the central nervous system in the form of instability of the psychophysiological status and behavior that are abnormal for such low energies [19]. The aim of this work was to analyze the influence of such EMR modes on non-associative learning of animals using the “open field” method.

MATERIALS AND METHODS

The experiments were conducted on male and female Wistar rats. At the beginning of the experiment the animals were 2.5 months old. The animals were kept in the vivarium, six per plastic cage. They were on a standard diet of pelleted feed and steamed grain with free access to water and food. All manipulations were carried out in accordance with regulatory legal acts on the humane treatment of laboratory animals [20].

An important indicator of the psychophysiological condition is OER tested by the “open field” method.

The method allows estimation of the emotional level (fear, anxiety, restlessness or inhibition, etc.), manifestation of the exploratory response, and motor and orientation activities. By repeated testing long-term memory changes and development of addiction responses can be recorded.

The “open field” in our experiments was a square (1.0×1.0 m), uniformly illuminated arena, bordered by opaque sides 30 cm high and divided into 16 equal squares (25×25 cm). The recording of behavioral reactions began from the moment the animal was placed in the arena (in the central zone represented by four middle squares). Since rodents in nature, when finding themselves in an open space, tend to rush to a shelter (to the corner of the arena), their prolonged stay in the central zone (the “lag phase” criterion) was regarded as a manifestation of retardation and stress. Other criteria for assessing the animals’ behavior in the “open field” test included the following: the number of intersections of squares in the center and along the periphery of the arena, vertical activity (rising on back legs), the number of entries into corners, stereotypical movements (grooming), and the number of acts of defecation (number of boluses). The testing duration was 10 minutes and the results were assessed separately for two five-minute periods. This was necessary due to the different psychophysiological status during the 10-minute testing, since normally the exploration of space in rats occurred mainly in the first five minutes, after which the exploratory response, anxiety, and motor activity decreased. The excessive activity throughout the testing cycle indicated that the animal was excited. Repeated testing after several days made it possible to judge the presence of a memory trace. In the case of a long-term memory violation in a rat, the indicators of motor activity and the duration of the lag phase upon repeated testing did not differ from those in the previous test. The rat did not recognize the environment and explored it as if for the first time.

The animals were exposed to microwaves in an anechoic chamber in the zone of the generated wave (about 3 m) from an ultra-high frequency radiation source (a block of ten generators with carrier frequencies uniformly distributed over the range of 1–4 GHz with close power values from each generator). During irradiation the rats were placed in lattice containers made of organic glass, which limited the free movement of the animals but did not interfere with their heat exchange, and the longitudinal axis of the body was oriented parallel to the E vector of the field. The microclimate conditions maintained in the anechoic chamber were as follows: air temperature $22.0 \pm 0.5^\circ\text{C}$, air humidity $50 \pm 5\%$, convection airflow about 0.5 m/s.

Two different exposure options were chosen for the study. In the first option the animals were irradiated 3 times with an interval of 3 days, 1 hour per day. The second option included 40 irradiation sessions, 5 days

a week on weekdays, with the daily exposure of 2 h, that is, the period of chronic exposure lasted about 2 months. In both cases, a pulsed mode was used: the total energy flux density in the pulse was $300 \mu\text{W}/\text{cm}^2$, pulse duration 25 ms, with return cycles of sweep (frequency change) of EMR pulse modulation in the frequency range close to EEG rhythms (from 6 to 1 Hz), cycle turnover time 30 s. The animals of control groups were subjected to the same manipulations as experimental animals, but with the source turned off.

The animals were tested one day before the start of irradiation (background indicators). The control and experimental groups were equal in terms of the initial activity. The animals that did not leave the central zone for an abnormally long time were excluded from further experiments.

All quantitative indicators were assessed using Student’s *t* test and Wilcoxon–Mann–Whitney *U* test.

RESULTS

Series 1. Evaluation of OER of Animals after Triple Ultra-High Frequency (UHF) Radiation

In this version, both male (Table 1) and female rats (Table 2) were exposed. The animals were tested 1, 11, 26, and 45 days after the end of the exposure.

When studying the behavior of males after irradiation, no disturbances in the behavior of rats were found: the OER of the experimental group did not differ from that of the control group.

During the testing of females, it was noticed that the animals of the experimental group leaved the central zone at the beginning of the experiment (the “lag phase” indicator) later than the animals of the control group. On days 1 and 11 these differences were not significant, but on day 26 they became statistically significant. The experimental group was divided into two subgroups based on this criterion: 8 animals out of 22 left the central zone noticeably later. The duration of their lag phase averaged 30.9 ± 15.7 s, whereas for the remaining 14 rats it was 1.6 ± 0.2 s. The differences between these subgroups of the experimental group were statistically significant. One can suggest that some of the animals in the experimental group experienced the state of partial stupor, freezing, and anxiety. However, 1.5 months after the end of irradiation the behavior of the rats in the experimental group was restored. It is noteworthy that a very small variation in the lag phase indicator was observed in the control female rats throughout the testing period. For the other indicators under study no statistical differences were recorded between the control and experimental groups. Both the control and experimental groups developed an addiction reaction as testing progressed: the number of times the rats stood up decreased and their overall motor activity decreased.

Table 1. Indicators of the orienting-exploratory response (OER) of male rats irradiated during three EMR sessions, in total for 10 minutes of observations ($M \pm m$)

Group	Indicators						
	Lag phase, s	Number of standing up	Grooming	Defecation	Entering corners	Numkber of crossing the squares in the center	Number of crossing the squares along the periphery
Baseline values (before exposure)							
C ($n = 19$)	3.4 ± 0.9	13.5 ± 1.8	9.4 ± 1.0	1.5 ± 0.3	12.2 ± 1.6	1.9 ± 0.4	32.7 ± 4.8
E ($n = 18$)	2.3 ± 0.3	10.9 ± 1.7	9.1 ± 1.0	1.4 ± 0.4	11.9 ± 1.7	1.8 ± 0.3	31.4 ± 4.9
First test (1 day after exposure)							
C ($n = 19$)	2.5 ± 0.4	7.4 ± 1.1	8.7 ± 1.1	0.7 ± 0.2	9.3 ± 1.4	1.8 ± 0.2	25.2 ± 4.3
E ($n = 18$)	2.7 ± 0.7	5.4 ± 1.0	6.4 ± 0.9	0.3 ± 0.1	8.3 ± 1.4	1.6 ± 0.3	22.1 ± 4.4
Second test (11 days after exposure)							
C ($n = 19$)	1.3 ± 0.1	9.1 ± 1.4	7.3 ± 0.7	1.2 ± 0.3	10.6 ± 1.6	1.8 ± 0.5	28.5 ± 4.6
E ($n = 18$)	1.3 ± 0.1	12.4 ± 1.6	5.9 ± 0.9	1.9 ± 0.4	13.0 ± 1.8	2.4 ± 0.6	35.9 ± 5.4
Third test (26 days after exposure)							
C ($n = 19$)	2.4 ± 0.5	7.0 ± 1.0	6.5 ± 0.7	0.9 ± 0.3	9.7 ± 1.4	1.3 ± 0.1	25.8 ± 3.8
E ($n = 18$)	1.9 ± 0.2	9.5 ± 1.3	5.9 ± 0.7	0.7 ± 0.3	12.4 ± 1.6	1.3 ± 0.2	34.9 ± 4.8
Fourth test (45 days after exposure)							
C ($n = 19$)	1.7 ± 0.2	9.0 ± 1.4	6.6 ± 0.7	2.5 ± 0.6	10.3 ± 1.4	1.8 ± 0.5	28.1 ± 4.2
E ($n = 18$)	1.9 ± 0.1	9.8 ± 1.3	4.5 ± 0.8	0.7 ± 0.3	14.2 ± 1.9	2.0 ± 0.4	40.1 ± 5.5

C—control group, E—experimental group.

Table 2. Indicators of the orienting-exploratory response (OER) of female rats irradiated during three EMR sessions, in total for 10 minutes of observations ($M \pm m$)

Group	Lag phase, s	Number of standing up	Grooming	Defecation	Entering corners	Number of crossing the squares in the center	Number of crossing the squares along the periphery
Baseline values (before exposure)							
C ($n = 22$)	2.4 ± 0.4	17.5 ± 1.9	5.3 ± 0.6	0.9 ± 0.3	26.9 ± 1.7	8.4 ± 1.3	76.9 ± 4.4
E ($n = 22$)	2.5 ± 0.4	15.8 ± 1.5	5.8 ± 0.5	0.9 ± 0.2	30.0 ± 1.8	9.3 ± 1.1	77.3 ± 5.1
First test (1 day after exposure)							
C ($n = 22$)	2.0 ± 0.8	22.8 ± 3.0	6.8 ± 1.0	1.3 ± 0.2	22.0 ± 2.4	5.8 ± 1.2	59.1 ± 7.1
E ($n = 22$)	8.9 ± 4.8	20.8 ± 2.5	6.3 ± 0.8	1.4 ± 0.4	23.8 ± 2.2	7.0 ± 1.1	65.2 ± 6.4
Second test (11 days after exposure)							
C ($n = 22$)	2.2 ± 0.3	8.0 ± 1.1	8.9 ± 1.1	1.2 ± 0.3	8.9 ± 1.2	2.9 ± 0.4	23.0 ± 3.3
E ($n = 22$)	11.0 ± 5.7	5.9 ± 1.1	8.2 ± 0.7	0.8 ± 0.2	8.0 ± 1.2	2.6 ± 0.3	20.3 ± 3.5
Third test (26 days after exposure)							
C ($n = 22$)	1.5 ± 0.1	9.3 ± 2.0	8.1 ± 1.3	1.4 ± 0.4	10.7 ± 1.9	3.4 ± 1.1	28.4 ± 5.4
E ($n = 22$)	$12.3 \pm 6.3^*$	4.9 ± 0.8	5.4 ± 0.9	0.5 ± 0.2	7.1 ± 1.0	1.5 ± 0.2	17.9 ± 2.9
Fourth test (45 days after exposure)							
C ($n = 22$)	2.0 ± 0.2	6.2 ± 1.6	3.3 ± 0.4	0.5 ± 0.2	8.5 ± 1.4	2.6 ± 0.7	21.9 ± 4.1
E ($n = 22$)	2.3 ± 0.1	5.8 ± 1.5	4.3 ± 0.5	1.0 ± 0.3	9.6 ± 1.5	2.0 ± 0.4	26.0 ± 4.5

C—control group, E—experimental group.

* Statistically significant differences compared with the control group at $p \geq 0.05$.

Table 3. Indicators of the orienting-exploratory response (OER) of male rats irradiated during forty EMR sessions, in total for 10 minutes of observations ($M \pm m$)

Group	Lag phase, s	Number of standing up	Grooming	Defecation	Entering corners	Number of crossing the squares in the center	Number of crossing the squares along the periphery
Baseline values (before exposure)							
C ($n = 19$)	3.9 ± 1.7	17.0 ± 3.3	6.7 ± 0.6	1.1 ± 0.3	23.3 ± 3.9	8.6 ± 1.5	66.8 ± 11.7
E ($n = 20$)	4.3 ± 1.1	15.3 ± 2.3	8.8 ± 1.1	1.6 ± 0.4	21.0 ± 3.3	8.0 ± 1.5	59.2 ± 10.0
First test (after 11 sessions of exposure)							
C ($n = 19$)	3.2 ± 0.4	8.7 ± 1.4	7.8 ± 0.7	1.4 ± 0.3	14.4 ± 2.1	4.4 ± 0.7	39.8 ± 6.3
E ($n = 20$)	19.1 ± 14.8	9.6 ± 1.5	6.7 ± 0.9	1.6 ± 0.6	15.7 ± 2.7	6.1 ± 1.1	43.9 ± 7.7
Second test (after 31 sessions of exposure)							
C ($n = 19$)	3.0 ± 0.6	7.5 ± 1.4	4.4 ± 6.9	0.6 ± 0.3	13.4 ± 2.1	3.7 ± 0.8	36.6 ± 6.1
E ($n = 20$)	10.7 ± 0.7	7.6 ± 1.1	5.2 ± 6.8	0.9 ± 0.3	13.8 ± 2.0	4.4 ± 0.7	39.0 ± 6.3
Third test (after 40 sessions of exposure)							
C ($n = 19$)	2.3 ± 0.5	6.4 ± 1.6	5.2 ± 0.7	1.2 ± 0.4	12.0 ± 2.2	4.2 ± 0.9	33.4 ± 6.8
E ($n = 20$)	$6.7 \pm 2.1^*$	7.8 ± 1.2	5.3 ± 0.6	0.6 ± 0.2	16.1 ± 2.4	5.2 ± 1.1	45.1 ± 7.3
Fourth test (two months after the end of exposure)							
C ($n = 19$)	1.9 ± 0.2	9.5 ± 2.1	5.2 ± 0.7	0.3 ± 0.1	16.1 ± 2.7	4.5 ± 0.9	45.0 ± 8.0
E ($n = 20$)	21.2 ± 14.4	8.9 ± 1.6	5.8 ± 0.6	0.7 ± 0.3	14.8 ± 2.5	3.6 ± 0.8	40.1 ± 7.4

C—control group, E—experimental group.

* Statistically significant differences compared with the control group at $p \geq 0.05$.

Series 2. Multiple Irradiations over 40 Sessions

In this version of the study only males were exposed. When testing the OER of male rats in the control and experimental groups throughout the test period, both during chronic irradiation and after the exposure, statistically significant differences were only found in the duration of the lag phase after the end of irradiation (the next day after the 40th irradiation session) (Table 3). There was also a tendency (at the level of $p = 0.1$) to the difference between the experimental and control groups after the 40th irradiation session in the first five minutes of observation for such indicators as the number of times they stood up, entries to the corners, and motor activity around the periphery of the arena.

No statistically significant differences were found between the experimental and control groups at all other testing periods, both during irradiation and two months after the its end. However, it is noteworthy that, as testing progressed, in the control group the time of leaving the central zone shortened and the dispersion of the “lag phase” indicator narrowed, which may imply that the control animals needed long time for memorization of the familiar environment. At the same time the experimental animals, both during and after irradiation, retained a long lag phase, although a division of the experimental group into animals with a short lag phase and animals with a long lag phase was

observed, which indicated that some of the experimental rats developed long-term memory impairments.

DISCUSSION

The question of influence on cognitive functions and, in general, on health of relatively weak but complexly organized electromagnetic fields formed by several simultaneously operating EMR sources with different carrier frequencies is a hot topic in the modern world. We tried to simulate such a situation in our work. We found that when using multiple carriers and modulation modes close to EEG rhythms, the impact of such EMR did not cause gross violations of the animals' OER, but it still affected the process of memorizing the animals' surroundings (arena territory). These changes did not last long. However, the results of this work, together with those of the previous one [19], showed that complexly organized electromagnetic fields can cause functional disturbances in the formation of associative and non-associative learning processes.

Our results are consistent with the study of the effects on cognitive functions of one, two, and three carrier frequencies of pulse-modulated EMR with the same average energy flux density [21]. It was found that the response from each frequency was within the physiological norm, but the effects increased with an

increase in the number of frequencies. The analysis showed that different degrees of synchronization of the brain's bioelectrical activity could be considered as one of the neurophysiological mechanisms for the formation of abnormal brain reactions reflected in the animal behavior.

Another possible mechanism for the effects of complex EMRs may be a direct damaging effect on the brain. In particular, the effects of long-term exposure to EMR in mobile communication modes on brain structures and the antioxidant status of the brain and, in parallel, on the behavior of animals in open fields and mazes were studied [18]. Following EMR exposure, histological examination revealed neurodegenerative changes in hippocampus and cerebral cortex, as well as significant changes in the levels of antioxidant enzymes. At the same time, a statistically significant deterioration in the animals' learning ability and an increase in their anxiety levels were observed. The results of this work allowed a conclusion that there is a direct link between EMR damaging effects on the brain and behavior.

We also found gender differences in the animals' response to a threefold exposure to EMR: female rats were more sensitive to electromagnetic wave irradiation. Other authors also found a more negative effect of EMR on females when used EMR in other modes [14, 22, 23]. This could matter in the sanitary and hygienic assessment of health effects of EMR.

CONCLUSIONS

The results of this work together with the data of our previous studies of the same EMR modes by the criterion of the conditioned avoidance response (CAR) test supported the hypothesis that repeated exposure to a complex EMR, close to the parameters of mobile communication, could cause functional disturbances in the behavior of animals, but these disturbances did not reach pronounced clinical significance. However, there is a risk that with constant exposure to EMR, as occurs, for example, in mobile phone users, such behavioral deviations may become entrenched and clinically significant.

AUTHOR CONTRIBUTION

Kolganova O.I.—collection and analysis of material, writing the article; Panfilova V.V.—collection and analysis of material, writing the article; Zhurakovskaya G.P.—collection and analysis of experimental data; Izmaytyeva O.S.—collection and analysis of experimental data; Chibisova O.F.—collection and analysis of experimental data; Zhavoronkov L.P.—general supervision and editing the article.

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ETHICS APPROVAL AND CONSENT TO PARTICIPATE

All manipulations were carried out in accordance with regulations on the humane treatment of laboratory animals stated in the FELASA Euroguide On the accommodation and care of animals used for experimental and other scientific purposes.

CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

REFERENCES

1. Khorseva, N.I., Grigor'ev, Yu.G., and Gorbunova, N.V., Psychophysiological indicators of children-users of mobile communication. Message 2. Results of four-year monitoring, *Radiats. Biol. Radioekol.*, 2011, vol. 51, no. 5, pp. 617–623.
2. Lerchl, A., Klose, M., Grote, K., Wilhelm, A.F.X., Spathmann, O., Fiedler, T., Streckert, J., Hansen, V., and Clemens, M., Tumor promotion by exposure to radiofrequency electromagnetic fields below exposure limits for humans, *Biochem. Biophys. Res. Commun.*, 2015, vol. 459, no. 4, pp. 585–590. <https://doi.org/10.1016/j.bbrc.2015.02.151>
3. Grigor'ev, O.A., Nikitina, V.N., Nosov, V.N., et al., Electromagnetic radiation safety russian national and international regulatory frameworks for radiofrequency electromagnetic fields, *Zdorov'e Naseleniya Sreda Obi-taniya*, 2020, vol. 10, no. 10, pp. 28–33. <https://doi.org/10.35627/2219-5238/2020-331-10-28-33>
4. Grigor'ev, O.A. and Zubarev, Yu.B., The effects of wireless communication electromagnetic energy influence on persons: predictions of the growth for conditioned morbidity. Their implementation and problems of evaluation, *Kontseptsii*, 2022, vol. 1, no. 1, pp. 3–17. <https://doi.org/10.34705/KO.2022.68.54.001>
5. Nikitina, V.N., Kalinina, N.I., Lyashko, G.G., Dubrovskaya, E.N., Plekhanov, V.P., et al., Special features of the architecture of 5G networks. Probabilistic forecasting of the impact of electromagnetic fields of radio frequencies on the population (literature review), *Gig. Sanit.*, 2021, vol. 100, no. 8, pp. 792–796. <https://doi.org/10.47470/0016-9900-2021-100-8-792-796>
6. Luk'yanova, S.N., *Fundamental'naya kharakteristika neuroeffektov slabyykh elektromagnitnykh vozdeystvii (ot neirona k otdelu mozga, TsNS, organizmu)* (Fundamental Characterization of Neuroeffects of Weak Electromagnetic Influences (From Neuron to Brain, CNS, Organism)), Moscow: Izd. Federal. Med. Biofiz. Tsentra im. A.I. Burnazyana, 2023.
7. D'Andrea, J.A., Chou, C.K., Johnston, Sh.A., and Adair, E.R., Microwave effect on the nervous system,

- Bioelectromagnetics*, 2003, suppl. 6, pp. s107–s147.
<https://doi.org/10.1002/bem10179>
8. Klose, M., Grote, K., Spathmann, O., and Streckert, J., Effects of early-onset radiofrequency electromagnetic field exposure (GSM 900 MHz) on behavior and memory in rats, *Radiat. Res.*, 2014, vol. 182, no. 4, pp. 435–447.
<https://doi.org/10.1667/RR13695.1>
 9. Shirai, T., Wang, J., Kawabe, M., Wake, K., Watanabe, S.-I., Takahashi, S., and Fujiwara, O., No adverse effects detected for simultaneous whole-body exposure to multiple-frequency radiofrequency electromagnetic fields for rats in the intrauterine and pre- and post-weaning periods, *J. Radiat. Res.*, 2017, vol. 58, no. 1, pp. 48–58.
<https://doi.org/10.1093/jrr/rrw085>
 10. Denisenko, S.A., Study on orientative activity of rats, which were prenatally exposed to low intensity centimetric range electro-magnetic radiation, *Mir Med. Biol.*, 2009, vol. 5, no. 2, pp. 99–104.
 11. Zibarev, E.V., Afanasev, A.S., Slusareva, O.V., and Bulavina, I.D., Exploratory studies of the influence of wireless equipment on the body of laboratory animals, *Gig. Sanit.*, 2017, vol. 96, no. 7, pp. 661–664.
<https://doi.org/10.18821/0016-9900-2017-96-7-661-664>
 12. Kadukova, E.M., Stashkevich, D.G., and Naumov, A.D., The influence of ionizing and non-ionizing radiation on the behaviour of female rats in the “open field” test, *Probl. Zdorov'ya Ekol.*, 2015, vol. 2, no. 44, pp. 55–59.
<https://doi.org/10.51523/2708-6011.2015-12-2-11>
 13. Navakatikyan, M.A., Changes in the activity and conditioned reflex activity of white rats during chronic microwave irradiation, *Radiobiologiya*, 1988, vol. 28, no. 1, pp. 120–125.
 14. Khirazova, E.E., Baizhumanov, A.A., Trofimova, L.K., et al., Effects of GSM-frequency electromagnetic radiation on some physiological and biochemical parameters in rats, *Byull. Eksp. Biol. Med.*, 2012, vol. 153, no. 6, pp. 791–794.
 15. Shiryayeva, N.V., Vaido, A.I., Pavlova, M.B., Surma, S.V., and Shchegolev, B.F., Electromagnetic radiation impact on the orienting-exploratory activity and cognitive functions of rat strains with contrasting excitability of the nervous system, *Integr. Fiziol.*, 2020, vol. 1, no. 2, pp. 123–132.
<https://doi.org/10.33910/2687-1270-2020-1-2-123-132>
 16. De Sere, R., Poutriquet, C., Games, Ch., et al., Repeated exposure to nanosecond high power pulsed microwaves increases cancer incidence in rat, *PLoS One*, 2020, vol. 15, no. 4, p. e226858.
<https://doi.org/10.1371/journal.pone.0226858>
 17. Dondoladze, Kh., Nikolaishvili, M., Museliani, T., et al., Impact of household microwave oven non-ionizing radiation on blood plasma cortisol levels in rats and their behavior, *Georg. Med. News*, 2020, vol. 306, pp. 132–137.
 18. Saikhedkar, N., Bhatnagar, M., Jain, A., Sukhwal, P., Sharma, Ch., and Jaiswal, N., Effects of mobile phone radiation (900 MHz radiofrequency) on structure and functions of rat brain, *Neurol. Res.*, 2014, vol. 36, no. 12, pp. 1072–1079.
<https://doi.org/10.1179/1743132814y.0000000392>
 19. Pavlova, L.N., Kolganova, O.I., Izmet'seva, O.S., et al., Influence of multiple and chronic exposure to electromagnetic radiation of the mobile communication frequency range on the behavior and cognitive functions of the rat brain, *Radiats. Biol. Radioekol.*, 2019, vol. 59, no. 6, pp. 619–626.
<https://doi.org/10.1134/S08698033119060080>
 20. *FELASA Euroguide on the Accommodation and Care of Animals Used for Experimental and Other Scientific Purposes*, London: The Royal Society of Medicine Press Ltd., 2007.
 21. Luk'yanova, S.N., Stepanov, V.S., and Torubarov, F.S., Studying the bioeffects of complexly organized electromagnetic impacts of low intensity, *Gig. Sanit.*, 2022, vol. 101, no. 5, pp. 515–521.
<https://doi.org/10.47470/0016-9900-2022-101-5-515-521>
 22. Izmet'seva, O.S., Pavlova, L.N., and Zhavoronkov, L.P., Experimental evaluation of the consequences of the chronic influence of electromagnetic radiation of the mobile communication range in antenatal rat development period, *Radiats. Biol. Radioekol.*, 2020, vol. 60, no. 1, pp. 63–70.
<https://doi.org/10.31857/S0869803120010099>
 23. Panfilova, V.V., Kolganova, O.I., and Chibisova, O.F., Analysis of the results of the prolonged influence of EMP on the cognitive functions of the progeny of irradiated rats, *Radiats. Biol. Radioekol.*, 2021, vol. 61, no. 2, pp. 174–179.
<https://doi.org/10.31857/S0869803121010094>

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