Original

Evaluating the Effect of Jammer Radiation on Learning and Memory in Male Rats

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ABSTRACT

Background: Previous studies shown that mobile phone can impairment of working memory in humans.

Objective: In this study, the effect of radiofrequency radiation emitted from common mobile jammers have been studied on the learning and memory of rats.

Material and Methods: In this prospective study, 90 Sprague-Dawley rats, were divided into 9 groups (N=10): Control, Sham^{1st} (exposed to a switched-off mobile jammer device at a distance of 50 or 100 cm/1 day, 2 hours), Sham^{2nd} (similar to Sham^{1st}, but for 14 days, 2 h/day), Experimental^{1st} -50 cm/1 day &100 cm/1 day (exposed to a switched-on device at a distance of 50 or 100 cm for 2 hours), Experimental^{2nd} (similar to experimental^{1st}, but for 14 days, 2 h/day). The animals were tested for learning and memory the next day, by the shuttle box. The time that a rat took to enter the dark part was considered as memory.

Results: Mean short-term memory was shorter in the experimental- 50 cm/1 day than control and sham- 50 cm/1 day (*P*=0.034), long-term memory was similar. Mean short- and long-term memory were similar in the experimental- 100 cm/1 day, control and sham- 100 cm/1 day (*P*>0.05). Mean short-term memory was similar in experimental- 50 cm/14 days, control, and sham- 50 cm/14 days (*P*=0.087), but long-term learning memory was shorter in the radiated group (*P*=0.038). Mean short- and long-term were similar among experimental-100 cm/14 days, control or sham 100 cm/14 days (*P*>0.05).

Conclusion: Rats exposed to jammer device showed dysfunction in short- and long-term memory, which shown the unfavorable effect of jammer on memory and learning. Our results indicated that the distance from radiation source was more important than the duration.

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Keywords

Electromagnetic Radiation; Spatial Learning; Memory; Non-ionizing Radiation

Introduction

Development and wide usage of cellular phone has raised concerns about the safety of humans exposed to radiation. Several studies have reported the unfavorable effects of radiofrequency electromagnetic radiation (RF-EMR) and have proposed it as a cause of oxidative stress and infertility in male rats [1, 2]. On the other hand, human studies have suggested the possibility of brain tumors in excessive users [3] as well as interference with the cognitive performance [4, 5]. Moreover, a wide range of adverse effects have been reported,

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including headache, fatigue, and skin irritation [6]. Thus, international guidelines have recommended limiting the amount of radiation exposure of mobile phones [7] and, the World Health Organization (WHO) has placed emphasis on studies related to electromagnetic field effects on humans [8].

Some countries use mobile phone jammers to block signals (including calls, and messages), for security reasons. These devices might cause unfavorable effects on different organs because they emit RF-EMR at the same frequencies as mobile phones [9]. As recently shown, short-term exposure to mobile phone jammers could reduce blood sugar levels in adult male rats [10]. However, their effects might vary based on several factors, such as proximity to the device and environmental factors [11]. Thus, several countries have prohibited the use of jamming devices, such as the United States Federal Communications Commission [12]. Although in several developed countries mobile phone jammers are still used, their safety is not clearly understood yet.

It has been previously shown that RF-EMR from mobile phones impairs brain function, especially in tasks that require attention and working memory [4, 5]. It has also been seen to alter regional cerebral blood flow, sleep, and waking behavior in humans [13, 14]. Proximity to mobile phones has been reported to affect neural activity, in an auditory task [15]. Considering the previous studies on the effects of mobile phone radiation and jammer radiation on human cognitive performance, and working each memory, the present study aimed to investigate the short- and long-term effects of mobile phone jammer radiation on the learning and short and long term memory of rats in different distances from a jammer device.

Material and Methods

Experimental design

In this prospective study, 90 mature male Sprague Dawley rats, weighing 200-250 g, were housed individually in 12/12-hour light/dark cycles, at room temperature (24 °C) (with free access to water, food, and standard rodent chow). Studied animals were handled in conformity with guidelines for the care and handling of laboratory animals provided by Shiraz Laboratory Animals Center in accordance with global standards for laboratory biosafety guidelines.

Then, the animals were randomly divided into 9 study groups, each consisting of 10 rats by randomization block:

1. The Control group underwent learning tests to assess normal memory and learning without any interventions. (reference group)
2. Sham 50 cm/1 day were exposed to a switched off jammer device at a distance of 50 cm for 2 hours once
3. Sham 50 cm/14 days were exposed to a switched -off jammer device at a distance of 50 cm for 14 days, 2 hours per day
4. Sham 100 cm/1 day were exposed to a switched- off jammer device at a distance of 100 cm for 2 hours once
5. Sham 100 cm/14 days were exposed to a switched - off jammer device at a distance of 100 cm for 14 days, 2 hours per day
6. Experimental 50 cm/1 day were exposed to a switched-on jammer device at a distance of 50 cm for 2 hours once
7. Experimental 100 cm/1 day were exposed to a switched-on jammer device at a distance of 100 cm for 2 hours once
8. Experimental 50 cm/14 days were exposed to a switched-on jammer device at a distance of 50 cm for 14 days, 2 hours per day
9. Experimental 100 cm/14 days were exposed to a switched-on jammer device at a distance of 100 cm for 14 days, 2 hours per day

The mobile jammer used in this study was an MB06-Mobile blocker, designed for 4-four different frequencies, including code division multiple access, digital cellular service, global system for mobile (GSM) communication, and third-generation which blocks the following frequencies: 850, 900, and 1800 MHz. The shielding radius was indicated to be 0-40 m on the jammer device.

Passive Avoidance Technique is a fast and simple test for evaluating learning and memory retention in animals. In this technique, rodents learn to stay in the bright side of the apparatus and don't arrive in the dark compartment [16].

The animals were tested for learning and memory status in the next day, using a shuttle box, containing two similar-sized light and dark parts and a valve connecting these two parts. Electric shock was delivered from the dark part of the floor to the animal's leg. At first, each animal was placed in the shuttle box and was allowed to move freely in the light and dark parts for 1-2 minutes. When the animal was familiarized with the environment, it was placed back into its cage. This step was called the *habituation phase*. After a few minutes, the rat was once again placed in the light part while the separating door was open allowing it to enter the dark part, then the door was shut and a 1.5 mA electric shock was delivered to the animal's leg. In the next stage, the rat was placed back in its cage. This session was called the *training phase*. This session was called the training phase. After a few minutes again this procedure was repeated, the rat was placed in the light part and the door was opened after 5 seconds, if the rat did not enter the dark part after 120 seconds, it was considered that the rat had learned, hence latency in entering the dark part is considered as the index of passive avoidance learning. When this test is performed a few minutes after the acquisition phase, it will be considered as short term memory. In the next step, *retention phase* was done, this procedure was repeated for learning retention 24 hours after the acquisition phase, it was considered to be the long-term memory. The retention phase shows the animal has learned and has the ability to retain and remember the learned task. It is considered as a long term memory or learning and retention. The length of time it takes the rat to enter the dark part or stayed in the same part was recorded within 10 minutes and compared among the study groups.

(The training phase was repeated, when the rat enters the dark part before 120 seconds, it was considered that the rat hadn't learnt, and if not, the rat was placed in the dark part for the electric shock to encourage learning. The repetition depended on the times required for learning; in most rats, the electric shock caused them to learn in the first try, while a few required two times to learn) [17-20].

The animals underwent different radiation patterns, Short term (2 h once) exposure and long term (2 h/day for two weeks) exposure to jammer device, before the beginning of the Passive Avoidance learning test (or shuttle box test).

Statistical analysis

Mean and standard deviation values of learning time were used to report the descriptive analysis of the variables. Based on the Kolmogorov-Smirnov test for normality of data distribution, mean values of learning time were compared using ANOVA or Kruskal-Wallis test amongst the nine studied groups. Post-hoc bivariate comparisons were applied when these tests revealed significant differences among the groups (Tukey test or Mann-Whitney with adjusted α). For the statistical analysis, the statistical software SPSS version 21.0 for Windows (SPSS Inc., Chicago, IL) was used. *P*-values smaller than 0.05 were considered to be statistically significant.

Results

Comparison between groups exposed for one day (Device switch-off or switch-on) at a distance of 50 cm- Sham 50 cm/1 day and Experimental group 50 cm/1 day- with the Control group showed that mean short-term memory was shorter in experimental 50 cm/1 day (157.8 s) than the control (339.6 s) and sham 50 cm/1 day (469.8 s) (P=0.034), whereas, long-term memory was similar (about 600 s) in these three groups (Tables 1 and 2).

Table 1: The results of short-term memory in different study groups

Groups(10 ratsineach group)	50 cm, 2 h/day (Mean±S.E)	100 cm, 2 h/day (Mean±S.E)	50 cm, 2 h/day For 14 days (Mean±S.E)	100 cm, 2 h/day For 14 days (Mean±S.E)
Experiment	157.8±79.8 Sec	174±71.9 Sec	254.9±94.1 Sec	420.8±91.2 Sec
Sham	469.8±69.1 Sec	433.9±74.6 Sec	492.5±71.7 Sec	390.6±85.6 Sec
Control	339.6±90.8 Sec	339.6±90.8 Sec	339.6±90.8 Sec	339.6±90.8 Sec
Test value(df)	6.786 (2)	5.584 (2)	4.881 (2)	6.54 (2)
P-value	*0.034	0.061	0.087	0.763

* *P*-values ≤0.05, Statistic test: Kruskal-Wallis test

Table 2: The results of the long-term memory in different study groups

Groups (10 ratsineach group)	50 cm, 2 h/day (Mean ±S.E)	100 cm, 2 h/day (Mean ±S.E)	50 cm,2 h/day For 14 days (Mean±S.E)	100 cm, 2 h/day For 14 days (Mean±S.E)
Experiment	587.2±12.8 Sec	600±0.0 Sec	398.2±84.3 Sec	489.6±73.6 Sec
Sham	593.8±3.2 Sec	588.3±11.7 Sec	594.0±6.0 Sec	582.0±13.1 Sec
Control	600±0.0 Sec	600±0.0 Sec	600±0.0 Sec	600±0.0 Sec
Test value(df)	1.114 (2)	2.00 (2)	6.544 (2)	2.246 (2)
P-value	0.573	0.368	*0.038	0.325

* *P*-values ≤0.05, Statistic test: Kruskal-Wallis test

In other section, the relation between groups exposed for one day (Device switch-off or switch- on) at a distance of 100 cm evaluated, Sham 100 cm/1 day, and experiment 100 cm/1 day- with the control group showed that mean short- and long-term memory were not statistically different (P>0.05) (Tables 1 and 2).

Comparison between groups exposed for 14 days at a distance of 50-cm -Sham 50 cm/14 days, and experiment 50 cm-14 days- with the control group showed that mean short-term memory was not statistically different in the experimental 50 cm/14 days than the control and sham 50 cm/14 days, (P=0.087), but mean long-term learning was significantly shorter in experiment 50 cm/14 days than the other groups (P=0.038) (Tables 1 and 2).

Comparison between groups exposed for 14 days at a distance of 100 cm- sham 100 cm/14 days, and experiment 100 cm/14 days -with the control group showed that mean short-term memory was not statistically different among these groups (P>0.05). Also, long- term memory was less in experiment 100 cm/14 days than sham 100 cm/14 days or control, but this difference was not statistically significant (Tables 1 and 2).

Studying the effect of duration of exposure on the short-term memory in radiated groups (1 day and 14 days) at a distance of 50 cm in comparison with control showed no statistically significant difference (P>0.05) (Table 3).

The effect of exposure duration on long-term memory in irradiated rats at a distance of 50 cm from jammer router revealed the inability or deficit in passive avoidance learning and retention relative to the control group (*P*=0.044) (Table 3).

Our findings show that the effect of exposure duration (2 h for one day or 14 days) on short- and long-term memory in irradiated rats at a distance of 100 cm from the jammer router was not statistically significant amongst the irradiated groups relative to the control group (*P*>0.05) (Table 4).

The effect of distance (50 &100 cm) on learning in the group irradiated once compared with the control group showed no statistically significant difference in short- or long-term memory (*P*>0.05) (Table 5). Also, to study the effect of distance (50 &100 cm) on the passive avoidance learning between the group that was exposed to radiation for 14 days and the control groups showed no statistically significant difference in short- or long-term memory (*P*>0.05) (Table 6).

Table 3: The effect of exposure duration on the short- and the long- term memory at 50 cm distance

Groups (10 rats in each group)	Short termmemory (Mean±S.E)	Longtermmemory (Mean±S.E)
Experiment (50 cm, 2 h/day)	157.8±79.8 Sec	587.2±12.8 Sec
Experiment (50 cm, 2 h/day For 14 days)	254.9±94.1 Sec	398.2±84.3 Sec
Control	339.6±90.8 Sec	600±0.0 Sec
Test value (df)	2.983 (2)	6.240 (2)
P-value	0.225	*0.044

* *P*-values ≤0.05, Statistic test: Kruskal-Wallis test

Table 4: The duration exposure effect on the short and long term memory at 100 cm distance

Groups (10 rats in each group)	Short termmemory (Mean±S.E)	Longtermmemory (Mean±S.E)
Experiment (100 cm, 2 h/day)	174.0±71.9 Sec	600.0±00 Sec
Experiment (100 cm, 2 h/day For 14 days)	420.8±91.2 Sec	489.6±73.6 Sec
Control	339.6±90.8 Sec	600±0.0 Sec
Test value (df)	2.523 (2)	4.138 (2)
P-value	0.283	0.126

Table 5: The distance effect on the short and long term memory for one-day exposure

Groups (10 rats in each group)	Shorttermmemory (Mean±S.E)	Longtermmemory (Mean±S.E)
Experiment (50 cm, 2 h/day)	157.8±79.8 Sec	587.2±12.8 Sec
Experiment (100 cm, 2 h/day)	174.0±71.9 Sec	600.0±0.0 Sec
Control	339.6±90.8 Sec	600±0.0 Sec
Test value(df)	3.437 (2)	2.222 (2)
P-value	0.179	0.329

Table 6: The distance effect on the short and long term memory for 14 days exposure

Groups (10 rats in each group)	Shorttermmemory (Mean±S.E)	Longtermmemory (Mean±S.E)
Experiment (50 cm, 2 h/day)	254.9±94.1 Sec	398.2±84.3 Sec
Experiment (100 cm, 2 h/day)	420.8±91.2 Sec	489.6±73.6 Sec
Control	339.6±90.8 Sec	600±0.0 Sec
Test value(df)	0.868 (2)	4.603 (2)
P-value	0.648	0.100

Discussion

The results of this study on the effect of mobile phone jammer on rat's memory and learning indicated that exposure to the jammer for 2 hours from a distance of 50 cm could significantly reduce rats' short-term memory, and radiation for 2 h/day for 14 days could significantly impair long-term memory (both P=0.03).

There are limited numbers of studies on the adverse effects of mobile phone jammers, as they are prohibited in many countries around the world; but in some countries, no such prohibition exists. The few studies on these effects have reported impaired muscle contraction [9], reduced blood sugar level [10], and reduced sperm motility [21] in rats by GSM jammers. May show similar effect on learning and memory. Results of the aforementioned studies on the effect of RF-EMR on memory and learning seem to be controversial. Some studies have claimed improved memory, while others have reported decreased memory or no difference in memory by being exposed to RF-EMF.

In line with our results, an animal experiment on rats determined impaired memory for temporal arranging of observing objects, by long-term exposure to GSM 900 MHz [22]. Also, 90 min/day exposure to GSM 1.8 GHz mobile phone signal resulted in malfunctioning of visual information processing mechanisms in the hippocampus, perirhinal, and entorhinal cortex of rats [23]. Nevertheless, other researchers have concluded no alterations in the learned responses of mice after 217 Hz RF exposure [24] or in the recognition memory by 900-MHz GSM [25]. These differences amongst animal studies can be attributed to the differences in the type of radiation emitted, durations, distance, and site of exposure as well as the types of tests used to study the rats' memory. In the present study, avoidance learning was measured by the shuttle box, which is considered as one of the primary tools that can evaluate memory retention in rodents. Passive avoidance learning tests the animal as it stays in the illuminated part and does not enter the dark part of the device to prevent from receiving a painful stimulus. Therefore, this technique assesses the skill and ability to learn and memory retention of the animals [26]. Human studies on the effect of RF-EMR on memory and learning have also concluded controversial results. Several studies suggested improvement in learning/memory by RF-EMR. Movvahedi et al. showed that short-term exposure to mobile phone radiation could improve the performance of students and their short-term memory with no difference in reaction time [27]. Another study by Sauter et al. found no evidence of the effect of GSM 900 and WCDMA mobile phone EMF on human cognition [28]. The results of the previous studies are inconsistent with the results of the present study, indicating shorter memory (mean time required for staying in the bright site and does not enter the dark part is shorter) in the irradiated rats. On the other hand, other studies have suggested that

RF-EMR significantly impair brain function. A study suggested poorer accuracy of working memory and shorter reaction time for a simple learning task in teenagers who used more mobile phone voice calls and overall faster and less accurate responses to higher levels of cognitive tasks [29]. Another study suggested decreased visual reaction and impairment of short-term memory by occupational exposure to radar microwave radiation (300 MHz-18 GHz) in military personnel [30]. Studies that investigated changes in electroencephalogram (EEG) have shown altered brain responses in exposure to RF-EMR [31]. A meta-analysis on neurobehavioral properties of Re-EMF emitted from GSM mobile phones on humans indicted small impact, but it had significant effects on attention and working memory, shorter reaction times, and less accuracy [32]. A recent review study also reported several neuropsychiatric effects by non-thermal microwave EMF from mobile phones, including sleep disturbances, headache, depression, fatigue, dysfunction in concentration/attention, memory changes, and irritability [33]. The results of the present study are in line with the above-mentioned studies, suggesting shorter memory in rats exposed to GSM jammer. These studies, along with the present study, necessitate the importance of paying attention to the issue of memory impairment by mobile phone radiation and jammer devices.

Another important finding of the present study is the fact that the duration of radiation from a 1-meter distance (2 h once or for 14 days) induced no statistically significant changes in short- and long-term memory, which can be due to the adaptation phenomenon in the animal. Thus, the present study suggests that short- and long-term exposure to GSM jammers had similar effects on memory/learning of rats. Various mechanisms have been suggested as the pathophysiology of changes in brain function by RF-RMR, including DNA damage, increased permeability of the blood-brain barrier, and modulation of receptor functions [34].

The present study evaluated the memory dysfunction of rats by GSM jammers in different durations and distances. There are some limitations, including a limited number of samples in each group, as well as the possibility of the effect of confounders, such as the thermal effect and fluctuations of radiation.

Considering, latency for the rat to enter into the dark area of shuttle box within time limitation means it has learned task or technique since it is against the innate tendency of the animal. Hence, short and long term exposure to non-ionizing radiation emitted from mobile jammer router as well as the distance length between jammer device and animal cages induced –inability in short- and long- term passive avoidance learning of rats [18-20].

Hence, radiation of mobile phone jammer for 2 h/day from a distance of 50 cm was seen to significantly reduce short-term memory in passive avoidance learning, and radiation for 2 h/day for 14 days at a distance of 50 cm significantly impaired long-term memory in passive avoidance learning. Since the effect of distance has been suggested to be more important than the duration, it is suggested to keep the recommended distance from devices that emit RF-EMR.

Conclusion

Our results have shown that exposure to Jammer radiations may cause dysfunction in short- and long term memories in the animals. It is notable that, the factor of distance from the radiation source finds more important than the exposure time. This was more significant in the long-term (14 days) of exposure. Since the novelty and importance of this work, the authors recommended more studies around the subject.

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Authors' Contribution

M. Yazdanpanhei has involved in the implementation of the project, as student thesis. A. Namazi has collaborated on the practical implementation of the project. MB. Shojaeifard has involved in the subject and the design of the project, the monitoring of the proper performance of the work and the analysis of data and project management and writing the article. S. Nematolahi has involved in statistical data analysis. S. Pourahmad has collaborated in determining of the correct statistical methods and interpretation of the obtained data. All the authors read, modified, and approved the final version of the manuscript.

Ethical Approval

The study was approved by the institutional review board and the local Ethics Committee of Shiraz University of Medical Sciences (Ethics Code: IR.SUMS.REC.1394.S63).

Conflict of Interest

None

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