

Does whole body exposure to GSM-950 MHz electromagnetic fields affect acquisition and consolidation of spatial information in rats?

M. Jadidi¹, S.M. Firoozabadi², A. Rashidy-Pour^{1*}, B. Bolouri³, Y. Fathollahi⁴,
A.A. Sajadi²

¹Laboratory of Learning and Memory, Department and Physiology Research Center, Semnan University of Medical Sciences, Semnan, Iran

²Department of Medical Physics, School of Medical Sciences, Tarbiat Modares University, Tehran, Iran

³Department of Medical Physics, School of Medicine, Iran University of Medical Sciences, Tehran, Iran

⁴ Department of Physiology, School of Medical Sciences, Tarbiat Modares University, Tehran, Iran

Background: This study was planned to examine the effects of whole-body exposure to GSM-950 MHz electromagnetic fields (EMFs) on acquisition and consolidation of spatial memory in rats using a water maze task. **Materials and Methods:** In experiment 1, the animals were given two blocks of five trials per day for three consecutive days in a water maze task. The interval between blocks was 4h. Before each training session, the animals were exposed to 950 MHz EMFs for 45 min with lower- (0.835 mW/cm²) or higher-power (1.166 mW/cm²) densities. In experiment 2, the animals were given two blocks of 5 trials with a 3 min interval between blocks. Immediately after the last trial, they were exposed to EMFs for 45 min with lower- or higher-power densities. In both experiments, 48 h after the last training day a 60 s probe test was done. **Results:** Results from experiment1 (pre-training exposure to EMFs) indicated no significant differences in performances of exposed and non-exposed groups either during acquisition (learning) or during probe test (memory retention). Results from experiment 2 (post-training exposure to EMFs) also indicated no significant differences among groups during acquisition or probe test. **Conclusion:** In these experiments, no effect of exposure to 950 MHz on acquisition or consolidation of spatial navigation of rats in a water maze was detected. *Iran. J. Radiat. Res.*, 2009; 7 (1): 57-62

Keywords: EMFs, 950 MHz wave, whole body exposure, spatial memory, morris water maze.

INTRODUCTION

Over the last decade, due to the development of new technologies, the number and diversity of appliances (TV sets, mobile phones, PC monitors, etc.) with sources of electromagnetic fields (EMFs) significantly

increased. Among the many appliances, due to a rapid expansion of mobile communications and reported symptoms such as headaches and head sensations, memory loss, etc by users ^(1, 2), the possible health impairing effects associated with exposure to EMFs from mobile handset and base station antenna are particular of public concern.

A few studies investigated the effects of exposure to EMFs on cognitive functions in human and experimental subjects, but the results are controversial. Some studies have revealed deficits on memory functions due to EMFs exposure ⁽³⁻¹³⁾, whereas other studies did not ⁽¹⁴⁻¹⁹⁾. In animal models, some studies reported deficits in two spatial learning tasks (Morris water maze and radial maze) after 45 min exposure to 2450 MHz EMF ^(20, 11). On the other hand, one study failed to show any impairment of memory performance of rats in a radial maze after 45 min of whole-body exposure to a 2450- MHz EMF ⁽¹⁴⁾. This discrepancy may be reflected in the experimental procedures such as task of studies, frequency of the applied EMFs, used inherent to exposure system (whole body versus head only), etc.

*Corresponding author:

Dr. Ali Rashidy-Pour,
Laboratory of Learning and Memory, Department and Physiology Research Center, Semnan University of Medical Sciences, Semnan, Iran.

Fax: +98 231 3354161

E-mail: Rashidy-Pour@sem-ums.ac.ir

Notably, the EMFs applied in the above mentioned studies are not those utilized the GSM protocol. The GSM mobile phone system in most countries has a frequency of either 900 or 1800 MHz (pulsed at 217 Hz, Band width of 200 KHz). The spectrum of 900 MHz has two band areas: 890-915 MHz that is specific for handset and 935-960 MHz that is specific for base station antenna. A few studies have focused on 900 MHz GSM signals as used in digital phone systems and failed to show any adverse effects of these signals on memory functions (1, 2, 18). To further clarify, this study investigated the effects of exposure to whole body exposure to GSM-950 MHz EMFs on memory processing in the water maze. The advantages of the present study are: 1) we used GSM-950 MHz EMFs, as a frequency in middle of base station band (935-960 MHz), which its effects on memory functions was not investigated yet. 2) Previous studies exclusively focused on the effects of the GSM EMFs on learning ability (acquisition), but in this study possible influences of the GSM EMFs was evaluated not only on acquisition but also on consolidation processes in the water maze.

MATERIALS AND METHODS

Naive male Wistar rats (225 ± 25 g) were used in this study. Rats were maintained on a 12-h light-dark cycle and with an ambient temperature of 21°C. They were housed in a maximum of 5 rats per breeding cage and allowed access to food and water ad libitum. All experiments were performed between 9:00 a.m and 13:00 p.m during the light cycle. All procedures were conducted in agreement with the National Institutes of Health Guide for care and use of laboratory animals. In each experiment (acquisition or consolidation), 4 separate groups ($n=11$ in each group) were used: control, sham-exposed, exposed to lower-power density (LPD) EMFs, and exposed to higher-power density (HPD) EMFs.

Morris Water Maze training

The behavioral training and testing was conducted in a water maze. The water maze was a blue circular pool (140 cm in diameter and 50 cm high) filled to a 25 cm depth with 22 ± 2 °C water (20). A circular glass platform (diameter: 11cm) was placed at the center of one quadrant (North-East quadrant) of the maze and submerged 3 cm below the surface of the water. The maze was located in a room containing several visual extra-maze cues. On each trial, the rat was placed into the water at one of the four cardinal points of the compass (N, E, S, W), which varied from trial to trial in a quasi-random order. The rat had to swim until it climbed onto the escape platform. If it failed to locate the platform within 60 s, it was guided there. The rat was allowed to stay on the platform for 20s, after which the animal was rotated one or twice being released from the next start position. After finding the platform, it was allowed to stay there for 45sec before the next trial. In experiment 1, the animals were given two blocks of five trials per day for three consecutive days. The interval between blocks was 4h. Before each training block, the animals were exposed to 950 MHz EMFs for 45 min with LPD (0.835 mW/cm^2) or HPD (1.166 mW/cm^2) densities (see below). In Experiment 2, the animals were given two blocks of 5 trials with a 3 min interval between blocks. Immediately after the last trial, they were exposed to EMFs for 45 min with LPD or HPD.

Two days later, the rats were returned to the water maze for a retention test. The rats were given a 60s probe trial during which the platform was removed. The parameters measured from probe test were the time spent (%) in each quadrant of the task, swim speed and total swim distance.

Exposure to EMFs

For whole body exposure to EMFs, a 950 MHz GSM simulator (pulsed at 217 Hz and band width of 200 KHz, made by Khaje-Nasir Toosi University, Tehran, Iran) was

used. It was connected to a 15 cm rod antenna fixed at the center of a circular plastic chamber (diameter = 30 cm). The animal could freely move inside the chamber. To prevent unknown exposure to reactive area of EMFs, some of the near field restricted by a plastic mesh (radius = 5 cm). The average power density inside the chamber was measured with RF meter (Narda 8716, USA) in different distances with 5 cm height from the base of antenna. With these records, the mean value for LPD was 0.835 mW/cm^2 , whereas for HPD was 1.166 mW/cm^2 . The average whole-body SAR (specific absorption rate) was determined by theoretical analyses and was 0.03 W/Kg for LPD and 0.05 W/Kg for HPD ⁽¹⁹⁾.

Statistical analysis

The training data was analyzed with a one way analysis of variance (ANOVA) with blocks or trials as repeated measures. Probe trial retention measures were analyzed with one way or two-way ANOVAs. Tukey's *post-hoc* test was performed to determine the source of detected significances. Values of $P < 0.05$ were considered as significant.

RESULTS AND DISCUSSION

Effects of exposure to GSM-950 MHz EMFs on acquisition of spatial memory in rats

All rats learned to locate the platform during training as indicated by decreasing escape latencies as training progressed (figure 1). A two way ANOVA (group \times block) with block as repeated measures showed significant effects of block ($F_{5,240} = 36.5$, $P < 0.001$), no significant effects of groups ($F_{3,240} = 2.77$, $P = 0.06$), and no significant interaction between two factors ($F_{15,240} = 1.127$, $P = 0.332$). Figure 2A illustrates the retention performance as assessed by time spent in the four quadrants. A two way ANOVA (group \times quadrant) showed significant effects of quadrants ($F_{3,160} = 79.24$, $P < 0.001$), no significant effects of groups ($F_{3,160} = 0.001$, $P = 1$), and no significant interaction between two factors

($F_{9,160} = 0.694$, $P = 0.714$). One-way ANOVA of swim path (figure 2B) and swim speed (figure 2C) data during the probe test revealed no significant differences among the groups ($F_{3,40} = 1.57$, $P = 0.211$; $F_{3,40} = 1.744$, $P = 0.173$, respectively). These findings indicated that exposure to 950 MHz waves of GSM mobile phone system with either LPD or HPD did not affect the acquisition of spatial information.

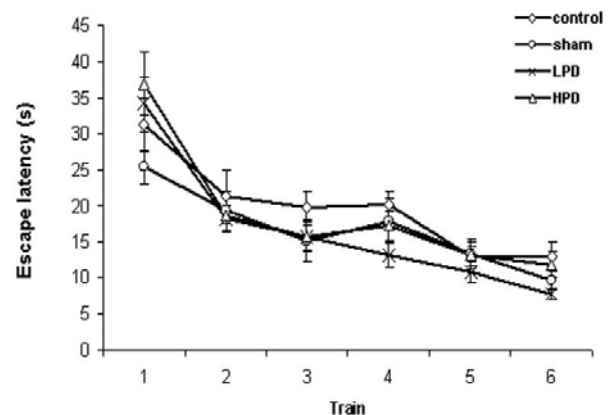


Figure 1. Effects of pre-training exposure to EMFs on acquisition of spatial information in a water maze. The animals were trained with two blocks of 5 trials per day during three consecutive days. Before each training block, the animals were exposed to 950 MHz EMFs for 45 min with lower-power (0.835 mW/cm^2) or higher-power (1.166 mW/cm^2) densities. The columns represent the mean (\pm S.E.M) escape latencies in experimental groups. $N = 11$ in each group.

Effects of exposure to GSM-950 MHz EMFs on consolidation of spatial memory in rats

All rats learned to locate the platform during training as indicated by decreasing escape latencies (figure 3) as training progressed. A two way ANOVA on latency data indicated a significant effect of trials $F_{9,400} = 11.74$, $P < 0.001$, lack of significant effects of groups $F_{3,400} = 2.02$, $P = 0.1$, and lack of significant interaction between both factors $F_{27,400} = 0.72$, $P = 0.848$. These findings indicate that all experimental groups had similar abilities during acquisition. Figure 4 illustrates the retention performance as assessed by time spent in the four quadrants. A two way ANOVA (group \times quadrant) showed significant effects of quadrants ($F_{3,160} = 39.89$, $P < 0.001$), no significant effects of groups ($F_{3,160} = 0.01$, $P = 1$), and no significant interaction between two

factors ($F_{3,160} = 3.298$, $P = 0.06$). One-way ANOVA of swim path (figure 4B) and swim speed (figure 4C) during the probe test indicated no significant differences among the groups ($F_{3,40} = 1.1$, $P = 0.357$; $F_{3,40} = 1.16$, $P = 0.334$, respectively). These findings indicated that exposure to 950 MHz waves of GSM mobile phone system in either LPD or HPD did not affect the consolidation of spatial information.

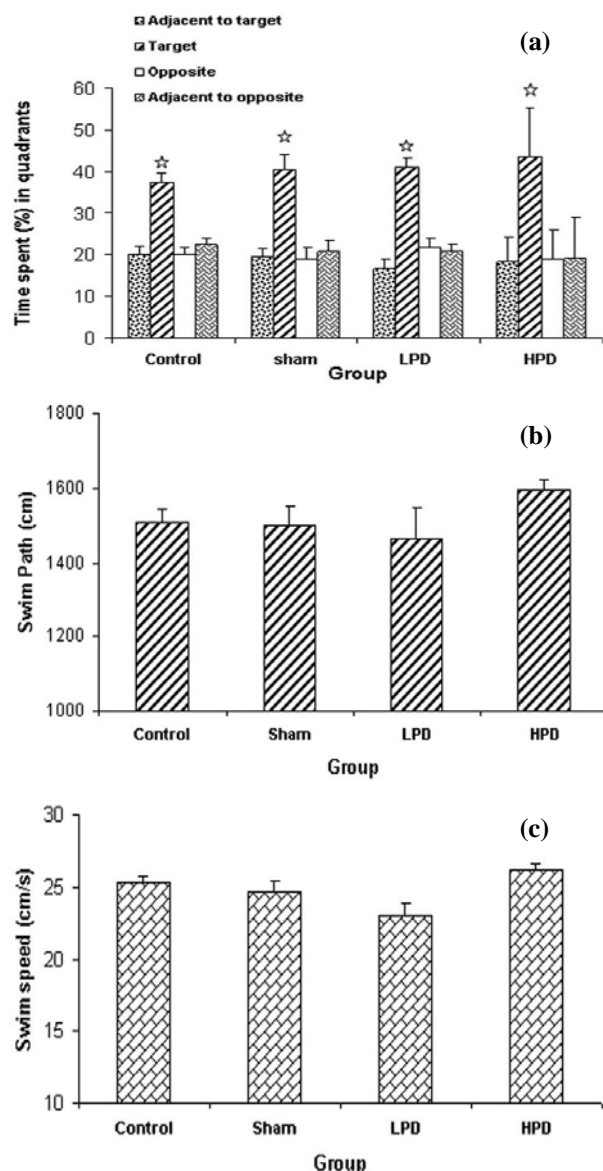


Figure 2. Probe trial results in rats pre-trained exposed to EMFs. No platform was present and rats received no exposure before the test. A: Mean \pm SEM time spent in each quadrant; B: swim speed, and C: traveled distance during the probe trial among four groups. The target quadrant was significantly more frequented than all others in all groups. * $P < 0.01$ versus other quadrants.

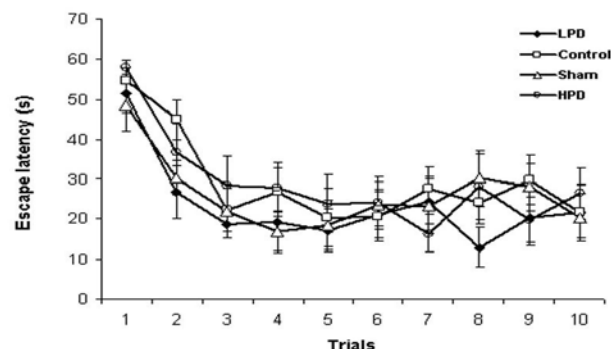


Figure 3. Place navigation learning curves in rats receiving post-training exposure to EMFs. The animals were given two blocks of 5 trials with a 3 min interval between blocks. Immediately after the last trial, they were exposed to EMFs for 45 min with lower-power (0.835 mW/cm^2) or higher-power (1.166 mW/cm^2) densities. Data represent the mean (\pm S.E.M) escape latencies in experimental groups. $N = 11$ in each group.

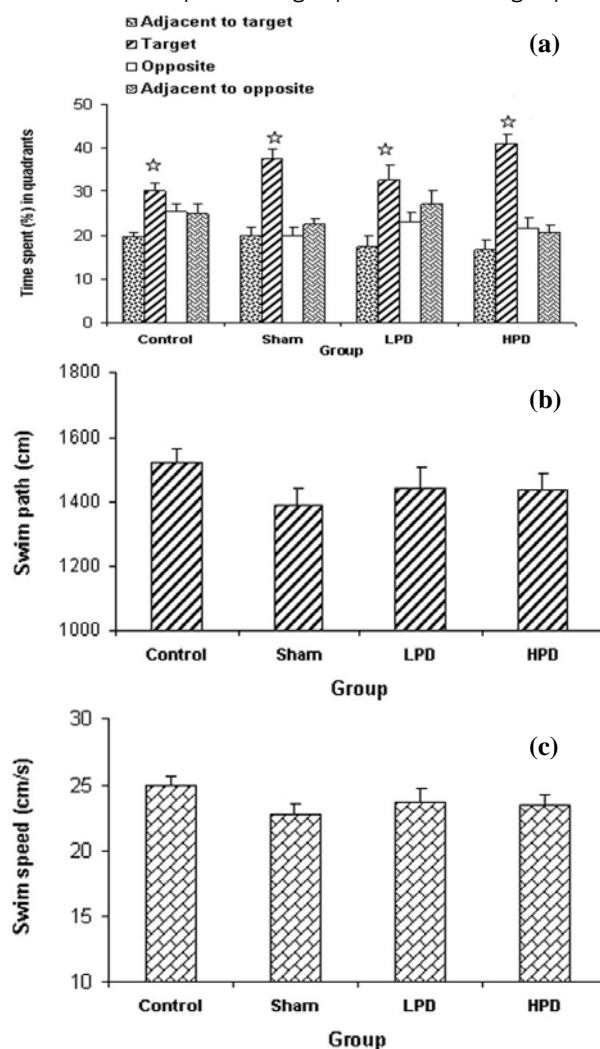


Figure 4. The effect of post-training exposure to EMFs on the consolidation of spatial memory. A: Mean \pm SEM time spent in each quadrant; B: swim speed, and C: traveled distance during the probe trial among four groups. The target quadrant was significantly more frequented than all others in all groups. * $P < 0.01$ versus other quadrants.

CONCLUSION

In the present experiments, acute whole body exposure to 950 MHz waves electromagnetic radiation from a GSM mobile phone system (pulsed at 217 Hz) did not affect either acquisition or consolidation of spatial navigation in rat.

The epidemiological studies have revealed that neurological symptoms occur in users of cellular telephones and in people who lived near the base station antenna. For example, some studies suggest that there is a direct relationship between the signs and calling time/number of calls per day (5, 6, 9, 10, 21, 22). In agreement with these results, studies in people lived in areas near the base station antenna showed irritability, depression, memory loss, concentration difficulties, vertigo, headache, sleep disturbances, feelings of discomfort and fatigue. The reported signs depend on duration of exposure, and the distance from antenna, and the antenna characteristics (23-25). Although the above mentioned and also similar studies are important to evaluate the effects of EMFs, systematic, well-controlled studies can only be carried in animal models.

The radio frequency radiations engage the spectrum of electromagnetic waves between 3 KHz - 300 GHz. This field can induce thermal or non-thermal effects on biological medium. Stimulation of excitable tissues will occur readily below 1 MHz, while thermal effects occur at higher frequencies (26). The mobile phones and their base station electromagnetic fields have low specific absorption rate that induce very low rise in brain temperature, thus, the possible biological effects of mobile phone systems on brain would be expected to be the non-thermal effects (27).

Our findings are in agreement with recent studies showing no effects of EMFs on performance of rat or mice in an 8-arm radial-maze task (9, 14, 19). Moreover, other studies showed that head only exposure to GSM 900-MHz EMFs did not alter rat's memory in spatial (radial maze) and

non-spatial tasks (16, 17). Our study is very similar to study by Sienkiewicz *et al.* (2000). They demonstrated that 45 min of whole body exposure to low levels of 900-MHz EMFs did not cause deficits in the performance in the radial arm maze. On the other hand, other studies have shown impairment of memory after exposure to EMFs. For example, the results of some recent studies indicated that 45 min exposure to a 2450-MHz EMFs induced deficits in spatial memory functions in Morris water maze and radial maze tasks (10, 28). It has been shown that low level microwave irradiation could alter the cholinergic transmission in the hippocampus and cortex (10). Since cholinergic system plays an important role in memory processing, it is claimed that exposure to 2450-MHz EMFs alter activity of this system in a way that produces impairment in spatial memory functions (9, 11). This discrepancy may be due to some subtle differences in the training paradigm (two blocks of five trials with a 3 min interval versus two blocks of 6 trials with a 4h interval), time of probe test (24 h versus 1 h after the last training) or the characteristics of the used electromagnetic fields (950 MHz pulsed with 217 pulses/s, average power density between 0.835 mW/cm² and 1.166 mW/cm² versus 2450-MHz pulsed with 500 pulses/s, average power density 2 mW/cm²), and duration of exposure (45 min versus 1 h immediately before each training session). Moreover, previous studies have shown that hyperthermia can induce memory impairment (29), thus it is more likely that impairment reported above can be due to consequences of a hyperthermia related to the whole body exposure (16).

In summary, the results of the present study indicate that exposure to 950 MHz waves emitted by a base station antenna had no effect on both acquisition and consolidation of rat's spatial memory in a water maze. Although this study was used as a model for understanding the effect of GSM EMFs on acquisition and consolidation phases of memory, further studies with a variety of intensities and durations of GSM

EMFs are needed to test their effect on memory processing. Moreover, with rapid increase in number of mobile phone users in the world and base station antenna in urban area, it seems that the knowledge about the effects of EMFs on human body especially human brain is a necessity.

ACKNOWLEDGMENT

This study was supported by Iran Telecommunication Research Center, Tarbiat Modares University and Semnan University of Medical Sciences.

REFERENCES

- Hocking B (1998) Preliminary report: Symptoms associated with mobile phone use. *Occup Med*, **48**: 357-360.
- Hermann DM and Hossmann KA (1997) Neurological effects of microwave exposure related to mobile communication. *J Neurol Sci*, **152**: 1-14.
- Croft RJ, Chandler JS, Burgess, AP, Barry RJ, Williams JD, Clarke, AR (2002) Acute mobile phone operation affects neural function in human. *Clin Neurophysiol*, **113**: 1623-1632.
- Haarala C, Bjornberg L, Ek M, Laine M, Revonsuo A, Koivisto M, Hamalainen H (2003) Effect of 902 MHz electromagnetic field emitted by mobile phone on human cognitive function: A replication study. *Bioelectromagnetics*, **24**: 283-288.
- Hocking B, Westerman R (2001) Neurological abnormalities associated with CDMA exposure. *Occup Med*, **51**: 410-413.
- Hocking B, Westerman, R (2003) Neurological effects of radiofrequency radiation. *Occup Med*, **53**: 123-127.
- Koivisto M, Krause CM, Revonsuo A, Laine M, Hamalainen H (2000a) The effects of electromagnetic field emitted by GSM phones on working memory. *Neuroreport*, **11**: 1641-1643.
- Koivisto M, Revonsuo A, Krause C, Haarola C, Sillanmaki L, Laine M, Hamalainen H (2000b) Effects of 902 MHz electromagnetic field emitted by cellular telephones on response times in humans. *Neuroreport*, **11**: 413-415.
- Lai H (2004) Interaction of microwaves and a temporally incoherent magnetic field on spatial learning in the rat. *Physiol Behav*, **82**: 785-789.
- Lai H and Carino M (1999) 60 Hz magnetic fields and central cholinergic activity: effects of exposure intensity and duration. *Bioelectromagnetics*, **20**: 284-289.
- Lai H, Horita A, Guy AW (1994) Microwave irradiation affects radial-arm maze performance in the Rat. *Bioelectromagnetics*, **15**: 95-104.
- Lass J, Tuulik, V, Ferenets R, Riisalo R, Hinrikus H (2002) Effects of 7 Hz-modulated 450 MHz electromagnetic radiation on human performance in visual memory tasks. *Int J Radiat Biol*, **78**: 937-944.
- Mann K, Roschke J (1996) Effects of pulsed high-frequency electromagnetic fields on human sleep. *Neuropsychology*, **33**: 41-47.
- Cassel JC, Cosquer B, Galiani R, Kuster N (2004) Whole body exposure to 2.45 GHz electromagnetic fields does not alter radial-maze performance in rats. *Behav Brain Res*, **155**: 37-43.
- Cosquer B, Galini R, Kuster N, Cassel JC (2005) Whole-body exposure to 2.45 GHz electromagnetic fields does not alter anxiety responses in rats: a plus-maze study including test validation. *Behav Brain Res*, **56**: 65-74.
- Dubreuil D, Jay T, Edeline JM (2002) Does head-only exposure to GSM-900 MHz electromagnetic fields effect the performance of rats in spatial learning tasks? *Behav Brain Res*, **129**: 203-210.
- Dubreuil D, Jay T, Edeline JM (2003) Head only exposure to GSM 900 MHz electromagnetic fields does not alter rats memory in spatial and non-spatial tasks. *Behav Brain Res*, **145**: 51-61.
- Preece AW, Davies-Smith A, Wesnes K, Butler S, Lim E, Valey A (1999) Effect of 915 MHz simulated mobile phone signal on cognitive function in man. *Int J Biol*, **75**: 447-456.
- Sienkiewicz ZJ, Blackwell RP, Haylock RG, Saunders RD, Cobb BL (2002) Low-level exposure to pulsed 900 MHz microwave radiation does not cause deficits in the performance of a spatial learning task in mice. *Bioelectromagnetics*, **21**: 151-158.
- Jadidi M, Firoozabadi SM, Rashidy-Pour A, Sajadi AA, Sadegi H, Taherian AA (2007) Acute exposure to a 50 Hz magnetic field impairs consolidation of spatial memory in rats. *Neurobiol Learn Mem*, **88**: 387-392.
- Oftedal G, Wilen J, Sandstrom M, Mild KH (2000) Symptoms experienced in connection with mobile phone use. *Occup Med*, **50**: 237-245.
- Sandstrom M, Wilen J, Oftedal G, Hansson Mild, K (2001) Mobile phone use and subject symptoms. Comparison of symptoms experienced by users of analogue and digital mobile phones. *Occup Med*, **51**: 25-35.
- Roosli M, Moser, M, Meier M, Braun-Fahlander C (2003) Health symptoms associated with electromagnetic radiation – A questionnaire survey. Mobile Phone Base Station and Health. Dublin, May 15th and 16th.
- Navarro EA, Segura J, Gomez-Perretta C, Portoles M, Maestu C, Bardasano JL (2003) About the effects of microwave exposure from cellular phone base stations: A first approach. Mobile Phone Base Station and Health. Dublin, May 15th and 16th.
- Santini R, Santini P, Danze JM, Le Ruz P, Seigne M (2002) Study of the health of people living in the vicinity of mobile phone base stations: I. Influences of distance and sex. *Pathol Biol*, **50**: 369-73.
- D'Andrea JA, Adair ER, Lorge JO (2003) Behavioral and cognitive effects of microwave exposure. *Bioelectromagnetics*, **6**: S39-S62.
- Ilhan A, Gurel A, Armutcu F, Kamisli S, Iraz M, Akyol O, Ozen S (2004) Ginkgo biloba prevents mobile phone-induced oxidative stress in rat brain. *Clinica Chimica Acta*, **340**: 153-162.
- Wang B and Lai H (2000) Acute exposure to pulsed 2450 MHz microwaves affects water-maze performance of rats. *Bioelectromagnetics*, **21**: 52-56.
- Mickley GA, Cobb BL, Mason PA, Farrell S (1994) Disruption of a pulsative working memory task and selective expression of brain c-fos following microwave-induced hyperthermia. *Physiol Behav*, **55**: 1029-1038.