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Behaviors and memory of Wistar rats exposed to electromagnetic waves at a frequency of 930 MHz

Medical Science

KEYWORDS : electromagnetic field, 930 MHz, GSM, rat, radial maze, hole board, memory.

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ABSTRACT

The mobile communication is based on the use of electromagnetic fields with frequencies between 300 MHz and 300 GHz. Many studies on humans and animals have suggested that these microwaves could interfere with cognitive functions. In the present study, we examined the effects of chronic exposure of 3 months to a mobile phone radiation of 930 MHz, produced by a wave generator bound to a communication system, on Wistar rats memory, in using several tests including the radial maze and the hole board. 60 rats were divided into 6 groups according to sex (males and females) and duration of exposure (controls, exposed 1h and 2h). The statistical analysis of results was performed by repeated measures of ANOVA test and Newman-Keuls test, which allows comparison of the means in pairs. The Results were considered statistically significant when the probability p is less than 0.05. We observed that females are more affected by the action of the electromagnetic waves compared to males. The mean of errors made by rats during the radial maze test increases significantly ($p<0,05$) for both sexes in the exposed rats compared to the controls. When testing the hole board, the mean number of holes explored by animals decreases significantly while the mean number of stumbling increases significantly in both sexes in the exposed rats compared to controls. In conclusion, the electromagnetic waves emitted by mobile phones may induce deficits at the working memory and reference, as well as the level of the exploratory and psychomotor capacities of Wistar rats.

Introduction

During the last decade, the research on the eventual effects of the electromagnetic waves dating back to the early years of 1960 (Asanov, and Rakov, 1966 ; Selmaoui, and al., 1997), have grown exponentially with the expansion of mobile telephony.

Based on the clinical and experimental data, it was asserted that the electromagnetic fields can produce in humans a variety of biological effects such as the headache (Frey, 1998 ; Hocking, 1998), the heat sensation, the sleep disturbances (Borbely, and al., 1999 ; Wagner, and al., 1998), the alterations in the electro-encephalogram (EEG) (Krause, and al., 2000 ; Wagner, and al., 2000) and the reaction time (Koivisto, and al., 2000a ; Koivisto, and al., 2000b), the risk of brain tumors (Hardell, and Carlberg, 2009 ; Khurana, and al., 2009), breast cancers (Caplan, and al., 2000 ; Loomis, and al., 1994) or leukemia (Rothman, and al., 1996), as well as behavioral problems in children exposed to electromagnetic radiation before and after birth (Divan, and al., 2008).

Although human studies are extremely important to evaluate the effects of electromagnetic waves, the experiences on animals bring us more information. In this respect, many studies have shown that exposure of rodents to the electromagnetic waves causes an alteration of the function of certain neurotransmitters (De Seze, and al., 1998 ; Mausset, and al., 2001), a permeability

of the blood-brain barrier (Hermann, and Hossmann, 1997) and a vascular permeability (Finnie, and al., 2001).

The effects on cognitive functions have also been studied in rodents. Indeed Lai, and al., (1994) reported that whole body exposure to microwaves for 45 min at a frequency of 2450 MHz may cause a delay in learning in the radial maze test. These results were subsequently extended by Wang and Lai (2000), who found that the exposure to microwaves for 1 hour at frequency of 2450 MHz may change the performance of Morris water maze. Besides, Cobb, and al., (2004) tried to reproduce these results in a radial maze at 12 arms, but without success. Other studies evaluated the effects of electromagnetic waves of 900 MHz on spatial and non-spatial memory, but failed to demonstrate the adverse effects of these signals used in mobile systems.

The present study was designed to determine the effects of electromagnetic waves GSM (930 MHz) emitted by a complex system of exposition on working memory and reference memory using the radial maze test (8 arms). The exploratory and psychomotor functions were evaluated by the hole board test.

Materials and methods

All procedures outlined below have been developed in our laboratory: Physiopathology and Molecular Genetics laboratory in Casablanca Ben M'Sik Science Faculty.

Animals:

The breeding, hosting and handling of animals were made in conformity with the guides of use of animals laboratory (National Academy of Science of Washington, 1996, Guide for the care and the use of animals laboratory).

Males and females Wistar rats aged 29 to 36 days with a body weight between 60 and 100 g, living in a controlled environment (12 hours of light and 12 hours of darkness). Temperature of the pet store is kept constant (22 ± 2°C) and the humidity is about 50%. Any variation of temperature and illumination is corrected as soon as possible.

The animals were fed with the standard diet (N° GPF81 of INAAM society, Casablanca, Morocco). The food is distributed daily at the same time. The tap water for drinking is available ad libitum. The bedding cages are changed three times per week. The rats are identified by a registered number by a permanent marker on the proximal tail part.

These rats were divided into six groups of five according to sex (males and females). The duration of exposure to electromagnetic fields (controls, exposed 1h and 2h) is illustrated in the diagram below. The rats were exposed to electromagnetic waves at a frequency of 930 MHz for 3 months on workdays.



Figure 1: Diagram representing the different groups of rats involved in the study

During the experimentation, the rats were divided in groups of five in the cages, and were housed inside a pyramidal sheet room.

Exposure system to electromagnetic fields:

The simulation of environmental of GSM coverage was performed by using a pyramidal structure having a ground base of 1.2 m x 1.2 m and a height of 2 m, the disposal of structure is vertical with a top opening which allows having an omnidirectional antenna allowing a homogeneous radiation of the electromagnetic field.

The radiation was generated by a repeater of 900–1800 MHz that allows reproducing the GSM signal, received from the GSM network and concentrating the radiation inside the test device, which plays the role of a Faraday cage, avoiding the interference with other external signals that can distort the envisaged study. The principle consists to reproduce of an environment similar to the real radiation, while ensuring that is studied only the radiation from GSM network.



Figure 2: The experimental device for the production of the signal GSM in the 900-1800 MHz band (Casablanca Ben M'Sik Science Faculty)

We used an amplifier ANDREW (PN: S-2-CPEUS-L-N, LEW POWER SP LIPPER, 800-2500 MHz).

* A receiver external antenna which can capture the GSM signal emitted by the nearest GSM station.
* An internal antenna transmitting at a power equivalent to -40 dbm and which can be positioned and oriented according to the desired needs.

The sealing of the device was tested and the signal level was measured by a trace post (Sony Ericsson Phone), with TENS software that performs the measurement in the 2G band 900 MHz. The temperature inside room was measured by a thermometer (digital interior – basic function).

During the exposure to the electromagnetic waves, the rats moved freely in a Plexiglas cage of 40 cm × 30 cm × 10 cm. The average power density is about 100 μW/cm^2 (19.4 V/m) in the cage. In the cell, the cage was placed in the level where an input power could generate the maximum field on the entire surface of the cage. Depending on the cell size, the level of the position of the cage, the input and output power, and the SAR (Specific Absorption Rate) were calculated.

Tests of memory and behavior:

After manipulation of rats in the conditioning room for 10 minutes, the animals were assigned to two experimental phases:

· A pre-test habituation of 14 days during which, the animals can explore freely and alternately the radial maze (*) and the hole board (HB). This phase aims to familiarize the rats with the experimental devices.
· A test phase of 3 months during which, the animals were exposed to an electromagnetic waves, and then they were placed alternately in the radial maze (10 min) and the hole board (5 min). The mean errors in the radial maze and the mean number of explored holes and stumbling in the hole board were evaluated. The Figure 3 schematizes the realized experimentation.

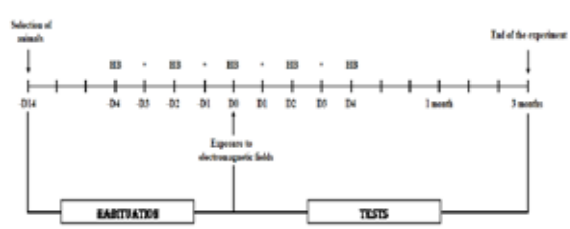

Figure 3: The experimental protocol used to study the effects of exposure of rats to the electromagnetic waves with HB = hole board and * = radial maze Radial maze:

Volume : 3 | Issue : 6 | June 2014 • ISSN No 2277 - 8179

Radial maze:

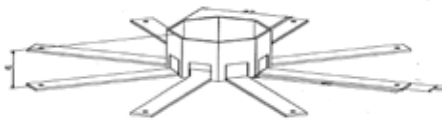

Figure 4: Schema of a radial maze

The radial maze wooden is constituted by an octagonal base of 69 cm, surrounded by a wall of 40 cm in height, provided with eight sash doors. Each door leads onto a corridor (60 cm long, 6 cm wide and 10 cm height) having a feed chute in its terminal part. This device allows assessing working memory and reference memory in rats.

We used the version working Memory - reference Memory of Packard and White (1990). During the habituation phase, each rat was familiarized with the maze for a period of 10 minutes. On the first day, the food pellets are placed on the floor of the central platform and four of eight corridors and in the feed wells of each these corridors. The rat is first placed on the central platform and the doors leading to eight corridors are open and the rat can explore the entire maze. During the days 2 to 14, the amount of available food pellets gradually decreases until there is more than a single intensifier concealed in the feed at the end of the four designated corridors well. During these days, the rats were daily subjected to learning the task.

- The rat consumed food pellets each of the four baited corridors.
- The rat made 16 visits corridors.
- 10 minutes have elapsed from opening the doors.

Hole board:
The hole board test (Boissier, and Simon, 1964) was designed to study the behavior and mainly the exploratory and the psychomotor skills of the rats facing a new environment. The exploratory skills reflect the animal state of mind. We define the exploration by the process that the head enter until the ears in the hole. The psychomotor skills was also evaluated by the number of stumbling made by the animal, if the rat gets up immediately after stumbling, this means that the psychomotor skills are not affected.

To do this, we used a board of 40X40 cm and of 1.8 cm thickness, of 16 drilled holes of 3 cm of diameter regularly spaced.

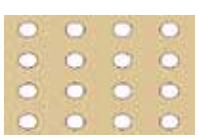

Figure 5: Schema of the hole board used (Boissier and Simon, 1964)

We can obtain satisfactory measures of habituation and emotional reaction with this device. Indeed, the manual quantification of these parameters is often more judicious.

The animal is placed in the center of the board. It counts the number of times that it plunges its head into one of holes after 1, 2, 3, 4 and 5 minutes. The mean of the explored holes during 5 minutes and the number of stumbling have been calculated.

The exploration function and the number of stumbling were also studied in control animals and in exposed to the electromagnetic waves for 1 and 2 hours.

Statistical analysis of results:
The statistical analysis was performed by repeated measures of ANOVA test and Newman-Keuls test, which allows comparison of the means in pairs. The results were considered statistically significant when the probability p is less than 5% ($p < 0.05$). The values of the measured parameters were expressed as a mean ± standard deviation.

Results

1- Radial maze test

In control animals, the mean number of errors decreased significantly ($p < 0.05$) between the first and the last day of the experiment, in both sexes.

In the exposed for 1 hour, we noticed a significant increase ($p < 0.05$) of the mean errors committed of the first on the last day of exposure to electromagnetic waves in male and female rats (figures 6 and 7). This increase is more important in the animals exposed 2h (Figures 6 and 7).

2- hole board test:

For the control animals and in both sexes, a significant increase ($p < 0.05$) in the mean number of explored holes by control rats, between the first and the last day of the experiment was observed (figures 8 and 9). While for the exposed 1h, a significant decrease ($p < 0.05$) in the mean number of explored holes by male and female rats between the first and the last day to exposure to the electromagnetic waves was noted. For 2h exposure, this decrease is more significant (Figures 8 and 9)

Our results also showed that the mean number of stumbling has increased in a significant manner ($p < 0.05$) in male and female rats exposed to electromagnetic waves compared to the controls at the end of the experiment, suggesting an affection of psychomotor activity of the rats (Figure 10)

The obtained results showed that the female rats are more affected by the action of electromagnetic waves compared to males for all parameters studied.

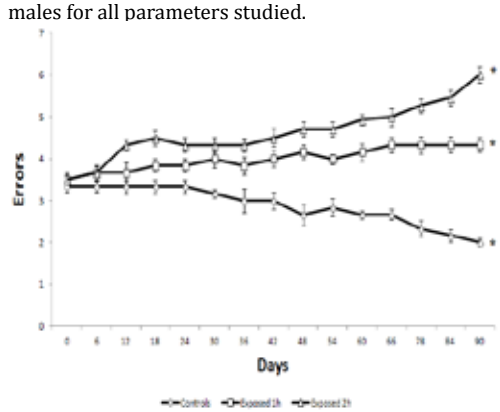

Figure 6: Evolution of the mean errors committed by the male control, exposed 1h and 2h rats when testing the radial maze for the duration of the experimentation; * = P < 0.05 (significant difference)

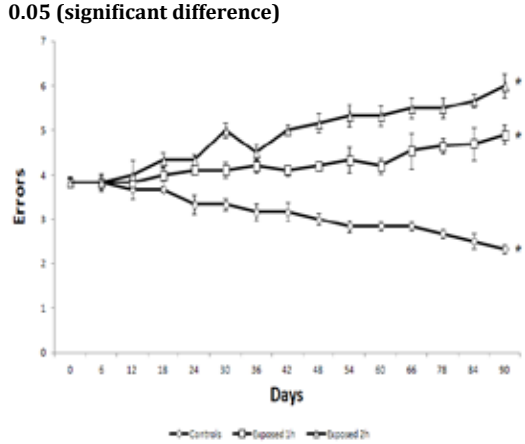

Figure 7: Evolution of the mean errors committed by the female control, exposed 1h and 2h rats when testing the radial maze for the duration of the experimentation; * = P < 0.05 (significant difference)

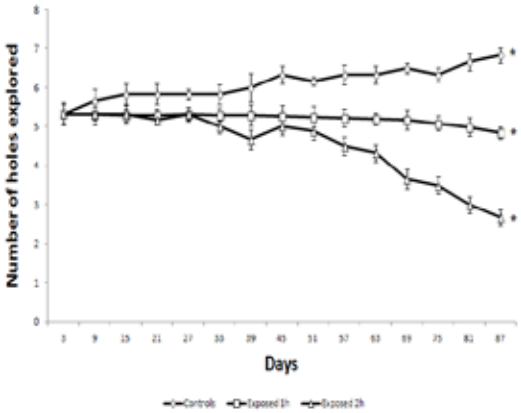

Figure 8: Evolution of the mean number of explored holes by the male control, exposed 1h and 2h rats during a hole board test; * = P < 0.05 (significant difference)

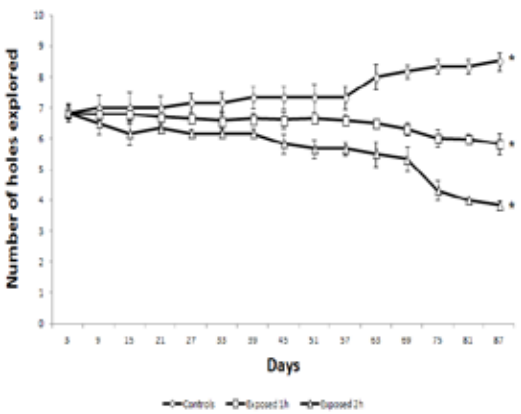

Figure 9: Evolution of the mean number of explored holes by the female control, exposed 1h and 2h rats during a hole board test; * = P < 0.05 (significant difference)

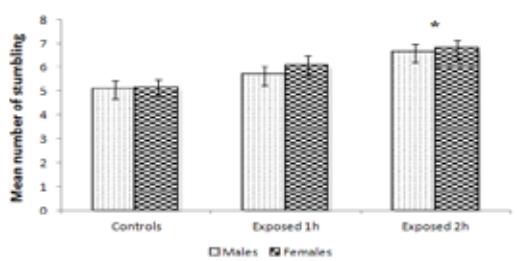

Figure 10: Evolution of the mean number of stumbling of male and female rats exposed to electromagnetic waves; * = P < 0.05 (significant difference)

Discussion

Although several works have studying the biological effects of the electromagnetic waves, only a few have been devoted to the behavior and the cognition. The results of these studies are inconsistent and sometimes contradictory (Boorman, and al., 2000 ; Bruner, and Harvey, 1998). Our results showed that the female rats are more affected by the electromagnetic waves emitted by mobile phones than males, which is caused by the particular sensitivity of females to the electromagnetic fields (Loomis, and al., 1994 ; Santini, 1998).

We observed that the exposure of rats to the electromagnetic waves of 930 MHz for 1 and 2 hours causes a significant decrease ($p < 0.05$) of explored holes number, and a significant increase ($p < 0.05$) in the number of stumbling in rats exposed to electromagnetic waves compared to the controls, which may reflect a decrease of curiosity and motor activity reflecting an anxiolytic state of these animals.

Our results also showed that exposure to the microwave causes a significant increase ($p < 0.05$) of the mean errors committed during the radial maze test in the rats exposed to the electromagnetic waves compared with controls, which could be an origin of alteration of the cognitive functions, of the working memory and the reference memory in rats. The error is only counted if the rats return to the same arm or put their four-legged inside a non-baited arm.

As in other studies, we chose to perform our experiment on the animals can move freely in their cages during exposure to electromagnetic waves (Narayanan, and al., 2009 ; Ferreira, and al., 2006), to minimize the possible effects of stress that can affect learning and memory (Joels, and al., 2006).

It has been suggested that memory deficits induced by the electromagnetic waves can be either thermal (D'Andrea, and al., 2003) mediation since in most studies these effects arise from SAR values beyond the standard reference of 2 W / kg, explained by the formation of a free radicals (Phillips, and al., 2009) and conformational changes of certain proteins (Caraglia, and al., 2005 ; Raber, 2008).

Our results are in agreement with other studies that have shown that exposure to electromagnetic waves of 900 MHz and 916 MHz may affect learning and memory in the exposed rats (Nittby, and al., 2008 ; Hao, and al., 2013). Moreover, the microwaves emitted by mobile phones at frequencies of 902 MHz (Koivisto, and al., 2000a ; Koivisto, and al., 2000b) and 890 MHz (Eliyahu, and al., 2006 ; Luria, and al., 2009) may affect human cognitive function. However, some authors have reveal that exposure to the electromagnetic waves of 900 MHz has no effect on the memory of mices (Sienkiewicz, and al., 2000) and rats (Dubreuil, and al., 2002 ; Dubreuil, and al., ; 2003). The differences between our results and those of other authors may be explained by the differences in experimental design and the duration of exposure to electromagnetic waves (1 and 2 hours per day for a period of three months against 45 minutes per day for a period maximum of 14 days).

Furthermore, Lai, and al., have reported deficits in memory performances after 45 minutes of exposure to an electromagnetic field of 2450 MHz (1994). They even attributed the deficit seen in the radial maze to disruption capacity of the working memory. These authors also suggested that exposure to a low frequency of electromagnetic waves could modify the cholinergic functions in the hippocampus and cortex of the rats (Lai, and al., 1987a ; Lai, and al., 1987b ; Lai, and al., 1989). Given the crucial role of the cholinergic function in cognition (Berger-Sweeney, 2003 ; Everitt, and Robbins, 1997), it was not surprising that the exposure to microwave modifies the memory performance (Lai, and al., 1994 ; Wang, and Lai, 2000).

The exposure to electromagnetic waves has occasionally been reported to induce stress (Ray, and Behari, 1990) and a modifying in a non-significant way of the locomotor activity in rats (D'Andrea, and al., 1980), two parameters that can influence the memory performances.

In rodents, an increase in the expression of Hsp70 protein (Fritze, and al., 1997), and a change in the expression of C-Fos protein (Bontempi, and al., 2002) after exposure to electromagnetic radiation have been reported.

Cobb, and al., (2004) failed to reproduce the results of Lai and colleagues, even if they used a protocol that was as close as possible to that of Lai et al.

Conclusion

Our results showed that the exposure for 1h or 2h to electro-

magnetic waves of 930 MHz for 3 months can affect the cognitive function, as well as the exploratory and the psychomotor skills of Wistar rats and that female are more affected than males.

REFERENCE

Asanov, T. P., & Rakov, A. I. (1966). IEEE | power engineering society special | publication, vol 10. Piscataway, New | Jersey. | Berger-Sweeney, J. (2003). The cholinergic | basal forebrain system during development | and its influence on cognitive processes: | important questions and potential answers. | Neurosci Biobehav Rev, 27(4), 401–411. | Boissier, J. R., & Simon, P. (1964). | Dissociation de deux composantes dans le | compartiment d'investigation de la souris. | Arch Int Pharmacodyn, 147(3), 372–387. | Bontempi, B., Dubreuil, D., Edeline, J. M., & | Jay, T. (2002). Effects of exposure to 900- | MHz GSM electromagnetic fields in rats: | changes in Fos protein expression without | deficit in cognitive performance. Third | Forum of European Neuroscience | Societies (FENS), Paris, 75-79. | Boorman, G. A., Rafferty, C. N., Ward, J. M., | & Sills, R. C. (2000). Leukemia and | lymphoma incidence in rodents exposed to | low-frequency magnetic fields. Radiat Res, | 153(5), 627–636. | Borbely, A. A., Huber, R., Graf, T., Fuchs, B., | Gallmann, E., & Achermann, P. (1999). | Pulsed high-frequency electromagnetic | field affects human sleep and sleep | electroencephalogram. Neurosci Lett, | 275(3), 207–210. | Bruner, L. J., & Harvey, J. R. (1998). | Synchronization of pacemaker cell firing | by weak ELF fields: simulation by a circuit | model. Bioelectromagnetics, 19(2), 92–97. | Caplan, L. S., Schoenfeld, E. R., O'Leary, E. | S., & Leske, M. C. (2000). Breast cancer | and electromagnetic fields – a review. Ann | Epidemiol, 10(1), 31–44. | Caraglia, M., Marra, M., Mancinelli, F., | D'Ambrosio, G., Massa, R., Giordano, A., | Budillon, A., Abbruzzese, A., & Bismuto, | E. (2005). Electromagnetic fields at mobile | phone frequency induce apoptosis and | inactivation of the multi-chaperone | complex in human epidermoid cancer | cells. J Cell Physiol, 204(2), 539–548. | Cobb, B. L., Jauchem, J. R., & Adair, E. R. | (2004). Radial arm maze performance of | rats following repeated low level | microwave radiation exposure. | Bioeletromagnetics, 25(1), 49–57. | D'Andrea, J. A., Gandhi, O. P., Lords, J. L., | Durney, C. H., Astle, L., Stensaas, L. J., & | Schoenberg, A. A. (1980). Physiological | and behavioral effects of prolonged | exposure to 915 MHz microwaves. J | Microw Power, 15(2), 123–135. | D'Andrea, J. A., Adair, E. R., & De Lorge, J. | O. (2003). Behavioral and cognitive effects | of microwave exposure. | Bioelectromagnetics suppl, 6, S39–S62. | De Seze, R., Fabbro-Peray, P., & Miro, L. | (1998). GSM radiocellular telephones do | not disturb the secretion of antepituitary | hormones in humans. Bioelectromagnetics, | 19(5), 271–278. | Divan, H. A., Kheifets, L., Obel, C., & Olsen, | J. (2008). Prenatal and postnatal exposure | to cell phone use and behavioral problems | in children. Epidemiology, 19(4), 523–529. | Dubreuil, D., Jay, T., & Edeline, J. M. (2002). | Does head-only exposure to GSM-900 | electromagnetic fields affect the | performance of rats in spatial learning | tasks? Behav Brain Res, 129(1–2), 203– | 210. | Dubreuil, D., Jay, T., & Edeline, J. M. (2003). | Head-only exposure to GSM 900-MHz | electromagnetic fields does not alter rat's | memory in spatial and non-spatial tasks. | Behav Brain Res, 145(1–2), 51–61. | Eliyahu, I., Luria, R., Hareuveny, R., | Margaliot, M., Meiran, N., & Shani, G. | (2006). Effects of radiofrequency radiation | emitted by cellular telephones on the | cognitive functions of humans. | Bioelectromagnetics, 27(2), 119–126. | Everitt, B. J., & Robbins, T. W. (1997). | Central cholinergic systems and cognition. | Annu Rev Psychol, 48(1), 649–684. | Ferreira, A. R., Knakievicz, T., Pasquali, M. | A., Gelain, D. P., Dal-Pizzol, F., | Fernandez, C. E., De Salles, A. A., | Ferreira, H. B., & Moreira, J. C. (2006). | Ultra high frequency-electromagnetic field | irradiation during pregnancy leads to an | increase in erythrocytes micronuclei | incidence in rat offspring. Life Sci, 80(1), | 43–50. | Finnie, J. W., Blumbergs, P. C., Manavis, J., | Utteridge, T. D., Gebski, V., Swift, J. G., | Vernon-Roberts, B., & Kuchel, T. R. | (2001). Effect of global system for mobile | communication (gsm)-like radiofrequency | fields on vascular permeability in mouse | brain. Pathology, 33(3), 338–340. | Frey, A. H. (1998). Headaches from cellular | telephones: are they real and what are the | implications? Environ Health Perspect, | 106(3), 101–103. | Fritze, K., Wiessner, C., Kuster, N., Sommer, | C., Gass, P., Hermann, D. M., Kiessling, | M., & Hossmann, K. A. (1997). Effect of | global system for mobile communication | microwave exposure on the genomic | response of the rat brain. Neuroscience, | 81(3), 627–639. | Hao, D., Yang, L., Chen, S., Tong, J., Tian, Y., | Su, B., Wu, S., & Zeng, Y. (2013). Effects | of long-term electromagnetic field | exposure on spatial learning and memory | in rats. Neurol Sci, 34(2), 157–164. | Hardell, L., & Carlberg, M. (2009). Mobile | phones, cordless phones and the risk for | brain tumours. Int J Oncol, 35(1), 5–17. | Hermann, D. M., & Hossmann, K. A. (1997). | Neurological effects of microwave | exposure related to mobile | communication. J Neurol Sci, 152(1), 1– | 14. | Hocking, B. (1998). Preliminary report: | symptoms associated with mobile phone | use. Occup Med, 48(6), 357–360. | Joels, M., Pu, Z., Wiegert, O., Oitzl, M. S., & | Krugers, H. J. (2006). Learning under | stress: how does it work? Trends Cogn Sci, | 10(4), 152–158. | Khurana, V. G., Teo, C., Kundi, M., Hardell, | L., & Carlberg M. (2009). Cell phones and | brain tumors: a review including the long- | term epidemiologic data. Surg Neurol, | 72(3), 205–214. | Koivisto, M., Revonsuo, A., Krause, C. M., | Haarala, C., Sillanmaki, L., Laine, M., & | Hamalainen, H. (2000a). Effects of 902 | MHz electromagnetic field emitted by | cellular telephones on response times in | humans. Neuroreport, 11(2), 413–415. | Koivisto, M., Krause, C. M., Revonsuo, A., | Laine, M., & Hamalainen, H. (2000b). The | effects of electromagnetic field emitted by | GSM phones on working memory. | Neuroreport, 11(8), 1641–1643. | Krause, C. M., Sillanmaki, L., Koivisto, M., | Haggqvist, A., Saarela, C., Revonsuo, A., | Laine, M., & Hamalainen, H. (2000). | Effects of electromagnetic field emitted by | cellular phones on the EEG during a | memory task. NeuroReport, 11(4), 761– | 764. | Lai, H., Carino, M. A., Horita, A., & Guy, A. | W. (1989). Low-level microwave | irradiation and central cholinergic | systems. Pharmacol Biochem Behav, | 33(1), 131–138. | Lai, H., Horita, A., & Guy, A. W. (1994). | Microwave irradiation affects radial-arm | maze performance in the rat. | Bioelectromagnetics, 15(2), 95–104. | Lai, H., Horita, A., Chou, C. K., & Guy, A. W. | (1987a). Effects of low-level microwave | irradiation on hippocampal and frontal | cortical choline uptake are classically | conditionable. Pharmacol Biochem Behav, | 27(4), 635–639. | Lai, H., Horita, A., Chou, C. K., & Guy, A. W. | (1987b). Low-level microwave irradiations | affect central cholinergic activity in the | rat. J Neurochem, 48(1), 40–45. | Loomis, D. P., Savitz, D. A., & Ananth, C. V. | (1994). Breast cancer mortality among | female electrical workers in the United | States. J Natl Cancer Inst, 86(12), 921– | 925. | Loomis, D. P., Savitz, D. A., & Ananth, C. V. | (1994). Breast cancer mortality among | femal electrical workers in the United | States. J Natl Cancer Inst, 86(12), 921– | 925. | Luria, R., Eliyahu, I., Hareuveny, R., | Margaliot, M., & Meiran, N. (2009). | Cognitive effects of radiation emitted by | cellular phones: the influence of exposure | side and time. Bioelectromagnetics, 30(3), | 198–204. | Mausset, A. L., De Seze, R., Montpeyroux, F., | & Privat, A. (2001). Effects of | radiofrequency exposure on the | GABAergic system in the rat cerebellum: | clues from semi-quantitative | immunohistochemistry. Brain Res, 912(1), | 33–46. | Narayanan, S. N., Kumar, R. S., Potu, B. K., | Nayak, S., & Mailankot, M. (2009). Spatial | memory performance of Wistar rats | exposed to mobile phone. Clinics, 64(3), | 231–234. | National Academy Press Washington, D.C. | (1996). Guide for the care and use of | laboratory animals. Institute of Laboratory | Animal Resources. Commission on Life | Sciences National Research Council. | Nittby, H., Grafstrom, G., Tian, D. P., | Malmgren, L., Brun, A., Persson, B. R., | Salford, L. G., & Eberhardt, J. (2008). | Cognitive impairment in rats after long- | term exposure to GSM-900 mobile phones. | Bioelectromagnetics, 29(3), 219–232. | Packard, M. G., & White, N. M. (1990). | Lesions of the caudate nucleus selectively | impair "reference memory" acquisition in | the radial maze. Behav Neural Biol, 53(l), | 39–50. | Phillips, J. L., Singh, N. P., & Lai, H. (2009). | Electromagnetic fields and DNA damage. | Pathophysiology, 16(2–3), 79–88. | Preece, A. W., Hand, J. W., Clarke, R. N., & | Stewart, A. (2000). Power frequency | electromagnetic fields and health. Where's | the evidence? Phys Med Biol, 45(9), 139– | 154. | Raber, J. (2008). AR, apoE, and cognitive | function. Horm Behav, 53(5), 706–715. | Ray, S., & Behari, J. (1990). Physiological | changes in rats after exposure to low | levels of microwaves. Radiat Res, 123(2), | 199–202. | Rothman, K. J., Chou, C. K., Morgan, R., | Balzano, Q., Guy, A. W., Funch, D. P., | Preston-Martin, S., Mandel, J., Steffens, | R., & Carlo, G. (1996). Assessment of | cellular telephone and other radio | frequency exposure for epidemiologic | research. Epidemiology, 7(3), 291–298. | Santini, R. (1998). Breast cancer in women, | high voltage power lines and melatonin. | Bioelectromagnetics Newsletter, 144, 5. | Selmaoui, B., Lambrozo, J., & Touitou Y. | (1997). Endocrine functions in young men | exposed for one night to a 50-Hz magnetic | field. A circadian study of pituitary, | thyroid and adrenocortical hormones. Life | Sci, 61(5), 473–486. | Sienkiewicz, Z. J., Blackwell, R. P., Haylock, | R. G., Saunders, R. D., & Cobb, B. L. | (2000). 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(3), 151–158. | Wagner, P., Roschke, J., Mann, K., Fell, J., | Hiller, W., Frank, C., & Grozinger, M. | (2000). Human sleep EEG under the | influence of pulsed radio frequency | electromagnetic fields. Results from | polysomnographies using submaximal | high power flux densities. | Neuropsychobiology, 42(4), 207–712. | Wagner, P., Roschke, J., Mann, K., Hiller, W., | & Frank, C. (1998). Human sleep under | the influence of pulsed radiofrequency | electromagnetic fields: a | polysomnographic study using | standardized conditions. | Bioelectromagnetics, 19(3), 199–202. | Wang, B., & Lai, H. (2000). Acute exposure | to pulsed 2450-MHz microwaves affects | water-maze performance of rats. | Bioelectromagnetics, 21(1), 52–56. | ||