Bioelectromagnetics 30:198–204 (2009)

Cognitive Effects of Radiation Emitted by Cellular Phones: The Influence of Exposure Side and Time

Roy Luria,[1,2]* Ilan Eliyahu,[3] Ronen Hareuveny,[3] Menachem Margaliot,[3] and Nachshon Meiran[1]

[1]Ben-Gurion University of the Negev, Beer-Sheva, Israel
[2]Department of Developmental Psychology, University of Padova, Padova, Italy
[3]Soreq NRC, Yavne, Israel

This study examined the time dependence effects of exposure to radiofrequency radiation (RFR) emitted by standard GSM cellular phones on the cognitive functions of humans. A total of 48 healthy right-handed male subjects performed a spatial working memory task (that required either a left-hand or a right-hand response) while being exposed to one of two GSM phones placed at both sides of the head. The subjects were randomly divided into three groups. Each group was exposed to one of three exposure conditions: left-side of the head, right-side, or sham-exposure. The experiment consisted of 12 blocks of trials. Response times (RTs) and accuracy of the responses were recorded. It was found that the average RT of the right-hand responses under left-side exposure condition was significantly longer than those of the right-side and sham-exposure groups averaged together during the first two time blocks. These results confirmed the existence of an effect of exposure on RT, as well as the fact that exposure duration (together with the responding hand and the side of exposure) may play an important role in producing detectable RFR effects on performance. Differences in these parameters might be the reason for the failure of certain studies to detect or replicate RFR effects. Bioelectromagnetics 30:198–204, 2009.

Key words: cellular phone; electromagnetic radiation; GSM; response times; spatial memory

INTRODUCTION

The widespread use of cellular phones has initiated research regarding the possible biological effects of exposure to radiofrequency radiation (RFR). This issue is of particular relevance because a considerable number of people are exposed to cellular RFR emitted in close proximity to the head. In addition, some modern cellular systems (including the GSM—Global System for Mobile communication that was examined in this study) operate in a pulsed mode in which data are accumulated and transmitted in short bursts. This should be borne in mind, since some studies have shown that modulated RFR may cause neurological effects even at low average power [Bawin et al., 1975; Foster, 1996]. Others, however, show no such effect [e.g., Green et al., 2005; Platano et al., 2007].

Previous studies that investigated RFR effects on central nervous system and cognitive functions revealed equivocal results. A study by Mann and Röschke [1996] found changes in the EEG pattern of sleeping subjects during an 8 h exposure to GSM RFR. The radiation source had an 8 W output and the power density at the head was estimated to be 0.05 mW/cm^2. An attempt to replicate these results by Wagner et al. [1998] has failed. Later studies reported an effect of RFR exposure from mobile phones on EEG alpha power. Recent work [Croft et al., 2008] found changes in the resting alpha of volunteers exposed to GSM mobile phones (Nokia 6110) for 30 min. The effect was larger at ipsilateral than contralateral sites over posterior regions. Furthermore, a study by Krause et al. [2000] tested the effects of cellular phones on the EEG during an auditory memory test. The findings indicated that EMF decreased the theta band EEG activity during the memory retrieval task, and increased the alpha band activity. Again, a replication study by Krause et al. [2004] failed to confirm these findings.

An epidemiological study by Oftedal et al. [2000] found that mobile phone users (GSM and NMT—Nordic Mobile Telephony) experienced a variety of

*Correspondence to: Dr. Roy Luria, Department of Developmental Psychology, University of Padova, Italy.
E-mail: roy.luria@unipd.it

Received for review 9 August 2007; Final revision received 9 September 2008

DOI 10.1002/bem.20458
Published online 17 November 2008 in Wiley InterScience (www.interscience.wiley.com).

symptoms (such as headaches, feelings of discomfort or warmth behind/around the ear), either during or shortly after a phone call. However, a study by Koivisto et al. [2001] that compared subjective symptoms and sensations (such as headaches, dizziness, fatigue, itching, tingling of the skin, redness and feelings of warmth on the skin) in a group that was exposed for 30–60 min to RFR to a control non-exposed group, failed to reveal any significant differences between these groups.

The effects of RFR on cognitive functions have been examined in several studies [e.g., Preece et al., 1999; Koivisto et al., 2000a,b; Haarala et al., 2003, 2004]. Preece et al. [1999] conducted tests on a variety of short-term memory, long-term memory and response time (RT) tasks. The subjects were exposed to RFR at 915 MHz (1 and 0.25 W output powers). The authors reported a reduction in RT, with the shortest RT in cases where the subjects were exposed to 915 MHz at 1 W. Koivisto et al. [2000a] conducted twelve different RT tests under exposure to 902 MHz at 0.25 W. In 3 of the 12 tests, a reduction in the RT was observed. Another study by Koivisto et al. [2000b] examined the effects on the working memory and revealed a reduction in RT under exposure. Once again, replicating those results posed problems. In two studies by Haarala et al. [2003, 2004] intended to replicate and extend the effect of RFR on cognitive functions, subjects performed cognitive and short-term memory tasks. These studies failed to replicate the Koivisto et al. [2000a,b] results.

In our previous study [Eliyahu et al., 2006] we examined the effects of exposure to RFR emitted by a standard cellular phone operation on human cognitive functions. Subjects switched between performing four distinct cognitive tasks—a spatial item recognition task, a verbal item recognition task, and two spatial compatibility tasks. All subjects performed all four tasks under three exposure modes: right-side of the head, left-side, and sham-exposure (counterbalanced within subject design). The experiment was divided into two 1-h sessions. We recorded the RTs and accuracy of the responses. Slowing of the left-hand response in the second part of the experiment under exposure of the left-side of the head was observed.

As noted above, a failure to replicate RFR effects was reported in several instances [Haarala et al., 2003, 2004]. Thus, the objective of the present study was to replicate our previous findings and to extend them. In particular, it was designed to examine the time dependence of the above-mentioned effect. Specifically, we divided the experiment into 12 blocks of 50 trials. The participants received a short break after each block. By averaging RTs separately for each block, we were able to track the time course of the RFR effect throughout the experiment.

We compared the RFR effect of left and right exposure sides on RTs during the spatial memory task adopted from our previous study. This task was chosen because it showed the largest RFR effects in our previous study [Eliyahu et al., 2006] and because the brain areas involved in performing this task had already been identified [Courtney et al., 1998]. In addition, only right-handed subjects were chosen as participants, since they show greater hemispheric specialization than left-handed [Amunts et al., 1996; Sasaki et al., 2007].

MATERIALS AND METHODS

Forty-eight healthy right-handed male subjects were randomly divided into three equal groups. The subjects in each group were exposed to *only one* of the three exposure conditions: left-side of the head, right-side, or sham-exposure. The experimental system was identical to the one described in our previous work: Each subject had two standard Nokia™ 5110 GSM cellular phones (Nokia, Helsinki, Finland) attached to both sides of the head by a specially designed non-conductive frame (Fig. 1). The cellular phones' transmitted power was controlled by an HP GSM test system model E6392B (Hewlett Packard, Palo Alto, CA). The phones were operated with test SIM cards (Wavetek, Ismaning, Germany). This system maintained the phones at either no transmission or full power transmission (890.2 MHz, 33 dBm = 2 W peak power, using the typical GSM pulse frequency of 217 Hz, pulse duration of 0.577 ms, duty cycle of 1/8, yielding 0.25 W average power). The maximum specific absorption rate (SAR) value reported for the Nokia 5110 model ranges from 0.54 to 1.09 W/kg, depending on the phone

Fig. 1. Subject with phone frame attached to the head.

position [DASY Test Report, 2000]. The phones were located in a position as similar as possible to that of typical use, and the antenna was located approximately 1.5 cm away from the subject's head. The communication between the phones and the test system was wireless, at an extremely low output power (0.01 mW), thus considered negligible. The phones were battery operated during the experiment. They were mounted on the subject's head before the first task and removed at the end of the experiment. The experiment was approved by the Ethical Helsinki Committee of the Soroka Medical School at Ben-Gurion University (Beer-Sheva, Israel). The subjects completed a questionnaire concerning intakes of tea, coffee, alcohol and the amount of sleep they had prior to the experiment. All participants reported adequate sleep in the night prior to the experiment, and they had not drunk excessively; thus, all subjects were included in the analysis.

The RF exposure regime was single-blinded, that is, the experiment manager was aware of the exposure mode while the subjects were not, since the phones were silent during the whole test. An opaque partition was placed between the experiment manager and the subjects during the experiment. The experiment manager controlling the cellular phones was not the one giving the instructions to the subjects, though both the experiment manager and the person giving instructions were aware of the exposure condition.

In the present experiment we studied only the cognitive task that showed the most significant effect of RFR on RT in the former study, that is, the spatial working memory task adapted from Courtney et al. [1998]. It was performed by all subjects (as presented in Fig. 2). The task proceeds as follows: three target "faces" are presented (for 650 ms each), in three random locations (out of eight possible). These eight possible locations are positioned as a 3 by 3 square (excluding the middle position). After an additional 3000 ms, another face appears in a random position. The subject has to decide whether the last face location matched any of the preceding three locations, and to respond by pressing a key with either the right-hand (to mark a match) or the left-hand (a mismatch), using the "/" key and the "z" key, respectively. Match and mismatch responses were randomly determined (on average, there were 25.36 match, 24.63 no-match in each block). The examined parameters were the RT and the percentage of correct responses made by the subjects.

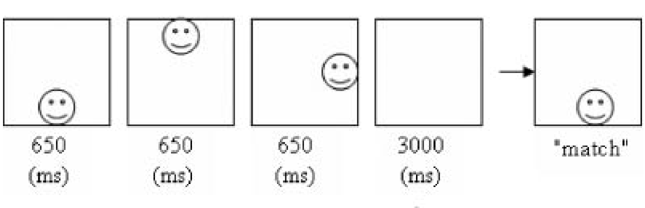

Fig. 2. The spatial working memory task: A target "face" is presented three times (for 650 ms each) in three random locations on the screen out of eight possible locations. After an additional 3000 ms, another face appears in a random position. The subject has to decide whether the last face location matches any of the preceding locations, and to respond by pressing a key with either the right-hand (when there is a match) or the left-hand (a mismatch).

The task utilized a standard laboratory PC-based software (Micro Experimental Laboratory 2.0^{TM}, Psychology Software Tools, Pittsburgh, PA) and the visual stimuli were presented on a 14 inch monitor, with a refresh rate of 60 Hz. In case of an erroneous response the computer emitted a 400 ms beep at 500 Hz.

After a short practice session (15 trials) one of the cellular phones was turned on (exposure groups only) and subjects performed 12 blocks of 50 trials each. The blocks were separated by a short break of a few seconds. The whole experiment typically lasted 1 h per subject.

Trials with RTs longer than 3 s or shorter than 100 ms were not included. Only those trials in which the response was correct were included in the RT analyses. These procedures excluded 4.4% of the overall observations. The Analysis of variance (ANOVA) on RT (in ms) as dependent variable included Group (right-side, left-side, and sham-exposure) as an independent between-groups variable, Block (1–12) and Responding Hand (left vs. right) as within-group independent variables. In addition, an ANOVA on accuracy (% correct) was performed including the same variables as the RT ANOVA. When appropriate, all P values for within variable were corrected according to Greenhouse-Geisser epsilon.

RESULTS

An ANOVA on the RT as dependent variable yielded significant main effects of Block, $F(11,495) = 6.86$, $P < 0.001$, indicating that when we average all other conditions (i.e., all exposure groups and both hands) there was an improvement of 88 ms from the first to the last block (probably due to practice, the overall RT was 944 ms (s.d. = 231 ms) in the first block and 856 ms (s.d. = 242 ms) in the last block), and Hand, $F(1,45) = 28.86$, $P < 0.001$, indicating that when we average all blocks and all exposure groups, right-hand responses were 50 ms faster than left-hand responses (the overall RT was 912 (s.d. = 214 ms) and 862 ms (s.d. = 214 ms) for the left and right hands, respectively). It should be noted that this last effect might have

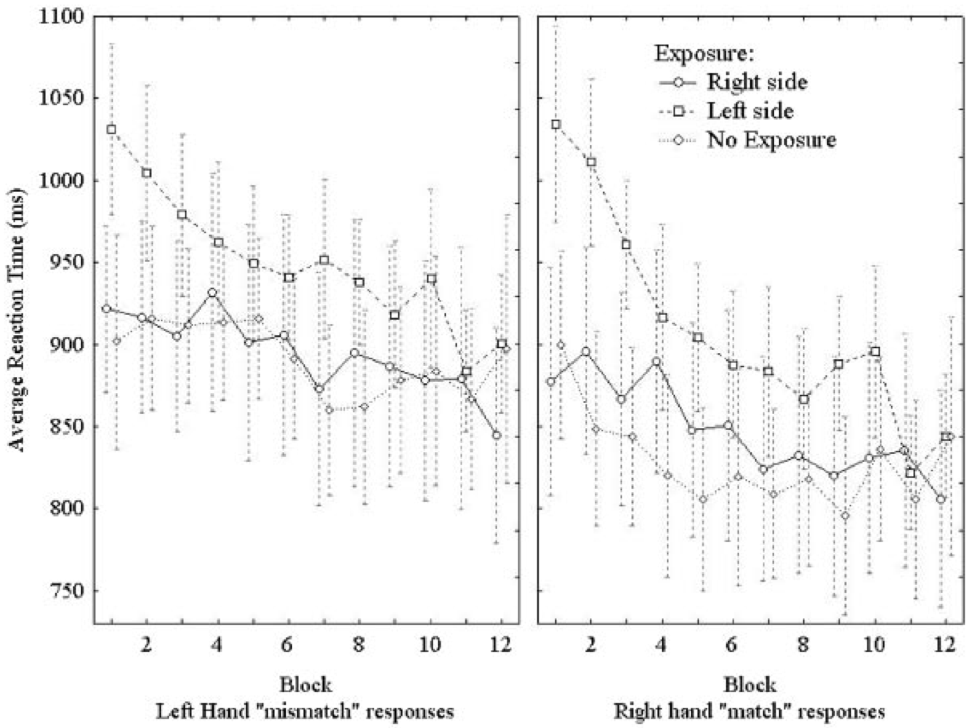

Fig. 3. Response time in ms for the right-hand (match) responses (**right panel**) and the left-hand (mismatch) responses (**left panel**) for the three exposure conditions: left-side of the head, right-side and sham-exposure. Error bars represent the standard error of the mean.

been the result of ''match'' responses being faster than ''mismatch'' responses, or of all subjects being right-handed.

Following Eliyahu et al. [2006] we present the average RTs, as a function of Group, Block, and Responding Hand in Figure 3 (triple interaction was not significant, $F(22,495) < 1$ $P = 0.79$. The 95% confidence interval, Masson and Loftus [2003] for this triple interaction was 48 ms). A visual inspection of the results reveals indeed that the RFR effect seems to be time dependent. Moreover, similar to Eliyahu et al. [2006] RFR slowed RT in left-side exposure only, and the right-side and sham-exposure showed comparable RT patterns. In fact, the differences between right-side and sham-exposure were far from being statistically significant, $t(45) = 0.24$, $P = 0.80$. In order to increase statistical power for further comparisons (and in line with our previous study) we averaged the right-side exposure and sham-exposure and treated them a single reference group.

In order to check the time dependence of the RFR effect (see Fig. 3) and following the results from Eliyahu et al. [2006] we devised a series of planned comparisons to test the specific exposure effects separately for each hand. During the first block, the average RT of the *right-hand* responses under the *left-side exposure* condition (thus engaging mostly the left cerebral hemisphere) was 146 ms longer than the right-side and sham-exposure groups combined, $t(45) = 2.11$, $P < 0.05$. This difference was significant across the second block as well $t(45) = 2.01$, $P < 0.05$, but it was slightly smaller, numerically, 139 ms on average. In the remaining blocks, the effect was no longer significant ($t(45) < 1$). Left-hand responses showed the same pattern, that is, right-hand responses under left-side exposure were slower (see Fig. 3); however, this trend was weaker and did not reach statistical significance for the first block ($t(45) = 1.56$, $P = 0.12$).

Please note that in the above analysis we used planned comparisons as recommended for replications. We argue that the use of post hoc comparisons is inappropriate in the present case because post hoc comparisons which prevent an increase in Type I errors (detecting an effect that does not exist) increase the probability of Type II errors, which involve missing a real effect. We wish to acknowledge the fact that the specific comparisons were non-significant when using post hoc (such as Bonferroni) criteria.

The ANOVA using accuracy (these data are not presented in the figure) as a dependent variable yielded only block dependence $F(11,495) = 2.82$, as a significant effect, indicating that accuracy was higher in the last block (0.965) compared to the first block (0.950), $t(45) = 2.80$, $P < 0.05$. We did not find any effect of RFR on accuracy, presumably because the accuracy level was very high.

At the end of each experiment, subjects were asked whether they had heard any noises. None of them reported any noise. Subjects also failed to judge which phone was operating during the experiment.

DISCUSSION

This experiment was designed to replicate and extend our previous work [Eliyahu et al., 2006] and specifically to investigate the time dependence of RFR effects emitted by cellular phones. We found that the average RT of the *right-hand* responses under *left-side exposure* condition was significantly longer than that under right-side exposure and sham-exposure averaged together, during the first two blocks only. *Left-hand* responses showed the same pattern, but it was weaker and non-significant. The present results confirmed the existence of an effect of exposure on RT and replicated some of the results obtained in our previous work; namely, in both experiments RTs of left-side exposed subjects were different from those of the sham- and right-side exposed ones. In addition, both studies demonstrate that RFR effects may be time dependent, that is, they can be observed only at specific phases of the experiment.

At this point there is no acknowledged explanation for the existence of cognitive effects of cellular phones, especially not for their possible attenuation over time. However, our results may point toward a possible mechanism: It is known that time dependence of cognitive tasks is governed at the first stages especially by practice (or learning) processes [Ackerman, 2007]. We found that RTs were prolonged at the beginning of the experiment but this effect diminished with time. Presumably, RFR influence is more prominent in the initial phases, when the task is unpracticed. The idea that practice may be more vulnerable to RFR, as well as to other sensory stimuli, is supported by other works on animals [Thomas et al., 1975; D'Andrea et al., 1977; Sanza and De Lorge, 1977; De Lorge and Ezell, 1980; Schrot et al., 1980; Saunders et al., 1991], showing reduced task acquisition under RFR exposure [Yamaguchi et al., 2003; Lai, 2004]. Note that Courtney et al. [1998] identified the superior frontal sulcus as an area specialized in processing the spatial task used in the present design. Interestingly, right and left hemispheres did not show similar patterns of activation, so the specific role of each hemisphere in processing the present task is not clear. Thus, we cannot determine the exact cause for the different pattern of results for the two hands.

Some differences in performance between the present and our former study [Eliyahu et al., 2006] should be mentioned. One of them is that in the current work the effect was significant for the right hand, and not significant (although, numerically evident) for the left hand, while in the previous research slowing was observed for the left-hand responses only. In addition, the time dependence of the effect was different: in the present experiment the RFR effects were apparent at the first two blocks of the experiment and decreased over time. Hence, RTs of the various groups became similar towards the end. However, in the previous work the average RTs of all exposure groups were similar in the first half of the experiment. The RT (of the affected hand of the left-side exposed subjects) increased over time, and in the second (and last) part became longer (relative to sham and right-side exposed condition). However, the differences in the time dependence between the two studies might have a simple explanation. First, in our previous study an effect was observed only in the second hour, while in this work the whole experiment lasted merely 1 h. Furthermore, the effect in this study was significant only in the first two blocks (which lasted approximately 5 min each), while (similar to our previous work) the average RT across the first hour showed no effect. Finally, it should be emphasized that contrary to the current experiment, the previous one was not designed to look for time dependent effects. Moreover, each subject switched between performing four different tasks and three exposure conditions as described in Eliyahu et al. [2006]. Consequently, the time dependence observed in the first experiment should be cautiously interpreted.

The origin of the differences between our result and other studies [Preece et al., 1999; Koivisto et al., 2000a,b; Haarala et al., 2003, 2004] that reported either a reduction or no significant change in the RTs, is unclear. These differences could be due to several reasons such as: Mobile phones' location and specific model, exposure methodology—right and left hemispheres, responding hand—left or right, exposure time, and the differences in the cognitive tasks.

In summary, we have found that experiment duration, exposure side and responding hand may have major influence on the detection of RFR effects. These parameters might explain the failure of certain studies to observe or replicate RFR effects. The inclusion of the above parameters in the design of any future experiment seems to be crucial. Looking at the overall average RT or accuracy might not reveal potential RFR outcomes, and more fine-grained time analysis might be required to observe it. In addition, the involvement of confounding factors (such as thermal heating or magnetic field emitted by the phones' circuits) must be examined.

ACKNOWLEDGMENTS

The authors thank Dr. Rafael Ruppin, Dr. Jean Koch, Dr. Yair Shamai, N.M. Yitzhak, and Hilla Karas for their helpful comments.

REFERENCES

Ackerman PL. 2007. New developments in understanding skilled performance. Curr Dir Psychol Sci 16:235–239.

Amunts K, Schlaug G, Schleicher A, Steinmetz H, Dabringhaus A, Roland PE, Zilles K. 1996. Asymmetry in the human motor cortex and handedness. NeuroImage 4:216–222.

Bawin SW, Kaczmarek LK, Adey WR. 1975. Effects of modulated VHF fields on the central nervous system. Ann NY Acad Sci 247:74–80.

Courtney SM, Petit L, Maisog J, Ungerleider LG, Haxby JV. 1998. An area specialized for spatial working memory in human frontal cortex. Science 279:1347–1351.

Croft RJ, Hamblin DL, Spong J, Wood AW, McKenzie RJ, Stough C. 2008. The effect of mobile phone electromagnetic fields on the alpha rhythm of human electroencephalogram. Bioelectromagnetics 29:1–10.

D'Andrea JA, Gandhi OP, Lords JL. 1977. Behavioral and thermal effects of microwave radiation at resonant and nonresonant wavelengths. Radio Sci 12:251–256.

DASY Test Report. 2000. Dosimetric assessment of the mobile Nokia 5110 with and without the PAM system devices according to the European CENELEC requirements. TTI-P-G 158 IMST.

De Lorge JO, Ezell CS. 1980. Observing responses of rats exposed to 1.28 and 5.62 GHz microwaves. Bioelectromagnetics 1:183–198.

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 27:119–126.

Foster KR. 1996. Interaction of radiofrequency fields with biological system as related to modulation, Proceedings of the International seminar on biological effects of non-thermal pulsed and AM RF EMF and related health risks, Munich, Germany, November 1996 (WHO/ICNIRP 3/97).

Green AC, Scott IR, Gwyther RJ, Peyman A, Chadwick P, Chen X, Alfadhl Y, Tattersall JEH. 2005. An investigation of the effects of TETRA RF fields on intracellular calcium in neurones and cardiac myocytes. Int J Radiat Biol 81:869–885.

Haarala C, Björnberg L, Ek M, Laine M, Revonsuo A, Koivisto M, Hämäläinen H. 2003. Effect of a 902 MHz electromagnetic field emitted by mobile phones on human cognitive function: A replication study. Bioelectromagnetics 24:283–288.

Haarala C, Ek M, Björnberg L, Laine M, Revonsuo A, Koivsto M, Hämäläinen H. 2004. 902 MHz mobile phone does not affect short term memory in humans. Bioelectromagnetics 25:452–456.

Koivisto M, Revonsuo A, Krause CM, Haarala C, Sillanmäki L, Laine M, Hämäläinen H. 2000a. Effects of 902 MHz electromagnetic field emitted by cellular telephones on response times in humans. Cogn Neurosci Neuropsychol 2:413–415.

Koivisto M, Krause CM, Revonsuo A, Laine M, Hämäläinen H. 2000b. The effects of electromagnetic field emitted by GSM phones on working memory. Cogn Neurosci Neuropsychol 8:1641–1643.

Koivisto M, Haarala C, Krause CM, Revonsuo A, Laine M, Hämäläinen H. 2001. GSM phone signal does not produce subjective symptoms. Bioelectromagnetics 22: 212–215.

Krause CM, Sillanmäki L, Koivisto M, Häggqvist A, Saarela C, Revonsuo A, Laine M, Hämäläinen H. 2000. Effects of electromagnetic field emitted by cellular phones on the EEG during a memory task. Cogn Neurosci 4:761–764.

Krause CM, Haarala C, Sillanmäki L, Koivisto M, Alanko K, Revonsuo A, Laine M, Hämäläinen H. 2004. Effects of electromagnetic field emitted by cellular phones on the EEG during an auditory memory task: A double blind replication study. Bioelectromagnetics 25:33–40.

Lai H. 2004. Interaction of microwaves and temporally incoherent magnetic field on spatial learning in the rat. Physiol Behav 82:785–789.

Masson MEJ, Loftus GR. 2003. Using confidence intervals for graphically based data interpretation. Can J Exp Psychol 57:203–220.

Mann K, Röschke J. 1996. Effects of pulsed high frequency electromagnetic fields on human sleep. Neuropsychobiology 33:41–47.

Oftedal G, Wilen J, Sandstrom M, Mild KH. 2000. Symptoms experienced in connection with mobile phone use. Occup Med 50:237–245.

Platano D, Mesirca P, Paffi A, Pellegrino M, Liberti M, Apollonio F, Bersani F, Aicardi G. 2007. Acute exposure to low level CW and GSM modulated 900 MHz radiofrequency does not affect Ba^{2+} currents through voltage gated calcium channels in rat cortical neurons. Bioelectromagnetics 28: 599–607.

Preece AW, Iwi G, Davies-Smith A, Wesnes K, Butler S, Lim E, Varey A. 1999. Effect of a 915 MHz simulated mobile phone signal on cognitive function in man. Int J Radiat Biol 75:447–456.

Sanza JN, de Lorge J. 1977. Fixed interval behavior of rats exposed to microwaves at low power densities. Radio Sci 12:273–277.

Sasaki H, Morimoto A, Nishio A, Matsuura S. 2007. Right hemisphere specialization for color detection. Brain Cogn 64:282–289.

Saunders RD, Kowalczuk CI, Sienkiewicz SJ. 1991. Biological effects of exposure to non ionizing electromagnetic fields and radiation. III. Radiofrequency and microwave radiation, National Radiological Protection Board, NRPB-R240.

Schrot J, Thomas JR, Banvard RA. 1980. Modification of the repeated acquisition of response sequences in rats by low level microwave exposure. Bioelectromagnetics 1:89.

Thomas JR, Yeandle SS, Burch LS. 1975. Modification of internal discriminative stimulus control of behaviour by low levels of pulsed microwave radiation. In biological effects of electromagnetic waves. Selected papers of the USNC/URSI annual meeting, boulder Colorado. 1975, volume 1 (Johnson CC, and Shore ML). US Department of Health, Education and Welfare. 1976. Rockville Maryland. HEW Publication (FDA) 77-8010: 201.

Wagner P, Röschke 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 19:199–202.

Yamaguchi H, Tsurita G, Ueno S, Watanabe S, Wake K, Taki M, Nagawa H. 2003. 1439 MHz Pulsed TDMA fields affect performance of rats in aT—Mazetask only when body temperature is elevated. Bioelectromagnetics 24:223–230.