

Study of Effects of Low Level Microwave Field by Method of Face Masking

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The aim of this study was to examine experimentally effects of low level, modulated microwaves on human central nervous system function utilizing the phenomenon of visual masking. Ten healthy volunteers, four males and six females, were exposed to electromagnetic field (450 MHz, 0.16 mW/cm²) with 7 Hz modulation frequency. Two photo series (visual stimuli) of unfamiliar, young male faces were presented to the subjects, one picture after another. All the photos were frontal views of unfamiliar faces, which could be recognized only by their unique combinations of features. The task was to identify the pictures from a group of six photos and to decide which order they were presented in. The phenomenon of visual masking is revealed as anamorphosis in subject's perception of two instantaneous visual stimuli presented within a short time interval. When both stimuli were to be recognized correctly and put in the right order, there was a statistically significant difference ($P < 0.05$) between the identification of the stimulus with microwave electromagnetic field and sham exposure. Recognition of both stimuli in a pair was better under the sham exposure conditions but the actual difference was only 5%. It was concluded that early stages of visual information processing are overwhelmingly robust and routine (and adaptively significant) activities, so that the low level 7 Hz modulated electromagnetic field effects exerted upon it are extremely weak. Bioelectromagnetics 26:571–577, 2005. © 2005 Wiley-Liss, Inc.

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INTRODUCTION

The increasing use of different electromagnetic devices in our environment has led to the growing concern about possible low level electromagnetic field effects on human health, mind, and behavior. An enormous amount of the laboratory and clinical studies has been done in recent years concerning short term effects on human brain electrical activity and cognitive functions. Several investigators have reported that low level microwave exposure produces alterations in the human EEG signal [Reiser et al., 1995; Mann and Rösche, 1996; Wagner et al., 1998, 2000; Borbely et al., 1999; Lass et al., 1999, 2001; Huber et al., 2000; Krause et al., 2000a; Hinrikus et al., 2004]. Lass et al. [1999, 2001] have found that a low power 450 MHz microwave field, pulse modulated at 7 Hz, causes changes in EEG. The authors reported suppression of EEG signal intensity in subjects exposed to the field. It is mentioned, however, that the varying character of the EEG makes it difficult to find small changes caused by the microwave field. Sleep EEG changes in non-REM sleep were detected by Huber et al. [2000]. Those authors observed an enhancement of the power density in the 9.75–13.25 Hz range. Usually the alterations in EEG occur together with variations in human mental state and performance in cognitive tasks.

Microwave electromagnetic field (EMF) effects on the mental activity and cognitive functions, including attention and memory, were studied by a research group from Finland. They have made several experiments on this topic [e.g., Koivisto et al., 2000a,b; Krause et al., 2000b; Haarala et al., 2003] during a 3 year period. The results obtained in the earliest studies suggest that the modulated EMF from digital GSM phones (902 MHz pulsed at 217 Hz) speeds up reaction times (RT) and decreases the time needed to perform mental arithmetic and working memory tasks. With a visual sequential letter task (n-back task) with healthy volunteers, where the subjects were asked to respond to each letter according to whether it appeared 0, 1, 2, or

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3 trials back, they found that response times to target letters were decreased under the effect of the radio frequency (RF) exposure. However, this effect was restricted only to the particularly demanding condition in which the three items had to be kept in memory, whereas there were no RF effects in the conditions with memory loads of two items or less [Koivisto et al., 2000b]. In their most recent study some improvements were made, such as multicentre testing and double blind design. The battery of nine cognitive tasks was performed under EMF and sham exposure and the same parameters were recorded. The RTs and the accuracy of answers were very similar to the earlier studies, but previous results were not replicated. Based on this result these authors postulated that EMF has no immediate effect on human cognitive functioning or that this putative effect is too small to be remarkable [Haarala et al., 2003].

James et al. [2003] studied the effects of mobile phone exposure on short and long term memory performance in male and female subjects. The volunteers were provided with a series of words to learn, their locations structured into a two dimensional shape, and given 3 min to memorize the words. The task was to draw the shape and place the correct words into appropriate boxes after a 12 min distraction task. After 1 week all the subjects were asked to redraw the shape and reproduce the words. Three experimental conditions were involved: no phone exposure, inactive phone exposure, and active phone exposure. The results suggest that males exposed to an inactive phone made fewer spatial errors than those exposed to an active phone condition, while females were largely unaffected. These results indicate that mobile phone exposure has an effect on human cognitive functioning and this effect appears to be sex-dependent.

Preece et al. [1999] reported a decrease in the choice reaction time as an effect of simulated mobile telephone transmission at 915 MHz during cognitive tests in man. Lee et al. [2001] studied EMF effects on human attention, comparing teenage mobile phone users and non-users. The results of their study suggest that exposure to the electromagnetic field emitted by mobile phones may have a mild facilitating effect on the attention functions.

Edelstyn and Oldershaw [2002] investigated the effects of acute mobile phone exposure on a range of tasks, which tapped capacity and processing speed within the attention system. They found significant differences between the exposed and sham exposed groups on two tests of attention capacity, digit span forwards and spatial span backwards, and one test of processing speed, serial subtraction. In all three instances, performance was facilitated following mobile phone exposure.

Lass et al. [2002] demonstrated that low level modulated microwave radiation (450 MHz, 7 Hz) affects human performance in typical neuropsychological tasks associated with attention and short term memory. They also reported that the effect of modulated microwave radiation varies in cognitive tasks of different level of complexity. The effect may cause a decrease in the number of errors for less complicated neuropsychological tasks and an increase in errors for more complicated tasks. The observed effects differed from subject to subject.

In this study, a new method to study the possible effects of low power modulated microwaves on central nervous system functioning is presented. Based on the above paper [Lass et al., 2002], the present study was built on the psychological phenomenon named visual masking, which is considered to be a cognitive task of a high level of complexity. The term visual masking refers, first, to a certain psychological phenomenon or effect, observable when two or more extremely short term visual stimulus images interact within a short interval; secondly, it refers to the special method of research based on this phenomenon [Bachmann, 1994]. Visual masking can be defined as impairment or total suppression of the perception of certain transient visual stimulus/image A as a consequence of the exposure of another visual stimulus/image B within the immediate spatiotemporal proximity to A, or in the partial or total spatiotemporal overlap with it. As a result of masking the stimulus could appear dimly (contrast reduction), change its perceivable figural characteristics, be perceived as fragmented or having undetermined quality (e.g., “something” is seen, however, it is impossible to tell what, precisely, is seen), or be lacking in perceptual experience at all. The last case can be termed as absolute masking.

In the masking experiment the main independent variables usually have to do with the temporal domain. The interval of time between the stimulus/image with regard to which response of a subject (observer) is required, and the stimulus/image which impedes the adequate perception of the former, is considered as the basic independent variable. The basic dependent variable is some measure of veridicality or quality of perception, such as perceived contrast or rate of correct recognition responses. The stimulus requiring a perceptual report is usually termed the target or test stimulus; the stimulus having detrimental effect and used for this purposefully is termed masker or masking stimulus. Using photos of faces in a masking test is especially good because a face is a very complicated social stimulus and very important in everyday communication.

The aim of this study was to investigate the possible effect of the modulated electromagnetic field

on the human visual perception. The hypothesis is that correct perception of faces is affected by EMF applied during stimuli presentation. The ability of correct identification of the target and masking stimuli and the order of their presentation in sham and exposed conditions was selected as the primary criterion.

MATERIALS AND METHODS

Participants

Ten adult subjects participated in the current single-blind study. The group of volunteers consisted of four male and six female subjects, aged between 19 and 32 years with a mean age of 23.10 years. All participants were healthy, without any known medical or psychiatric disorders, and had normal or corrected to normal visual acuity. Subjects were asked to abstain from caffeine and alcohol on the day before the experiment. All the participants gave their informed consent before the start of the experiment. The study protocol was approved by the local ethical committee of research on human beings.

Method

The subjects were presented with two successive photos of a male face and the task of a subject was to identify both pictures from a group of six alternative photos. The photos were presented for the durations and with stimulus onset asynchrony (SOA) specially adjusted for optimum level of performance (see “Stimulus Presentation” section). The tests were carried out in 16 sessions per subject. Each session consisted of a sequence of EMF and sham exposure. The random distribution was used for starting the sessions either with EMF exposure or with sham exposure. If the first session started with EMF then next session started without EMF exposure and vice versa. Each subject had a total of eight sessions with EMF and eight sets without EMF (sham exposure). Each set consisted of 50 trials; altogether a subject made 800 trials, 400 with and 400 without EMF exposure. To avoid subjects becoming aware about whether they were exposed to EMF or not, in both experimental conditions (EMF vs. sham) the antenna was located at 10 cm from the skin of the right side of the head.

All subjects performed the same experiment under the same conditions and instructions. The experiment for a subject was carried out during several days over a 1 month period. Each subject participated 2–8 sessions during 1 day. There was at least a 15 min break between the sessions for a subject. The first session was a practice session where the task was explained and the participants had 5–10 min for training. They were

asked to calm down and carry out the task as seriously and accurately as they could. In case they were not sure about the answer they were asked not to respond.

The participants were sitting in front of the computer monitor with a viewing distance of approximately 50 cm. As they had to respond by the help of a mouse, only one hand (left or right) was used to produce responses. In the training phase of the test the participants were asked about their vision and handedness. During the pauses between the sessions the subject was asked how he/she was feeling, whether he/she felt tired, and if he/she was able to continue the test without discomfort. If the subject could not perform the task, his/her sessions were postponed to another day. Subjects with permanent problems were excluded from the study. The experiment was carried out in a dimly lit, sound isolated room. To avoid social stress, subjects were left alone in the room during the session.

Stimulus Presentation

Special software was developed in order to present two photos of human faces and to register subject's ability to identify the images afterwards. The stimuli were 60 black and white photographs of unfamiliar, young male faces that were presented in the center of a computer monitor on a gray background. All stimuli were frontal views of faces, which were expressionless and without extraneous cues of identification (glasses, beards, etc.), so that they could be recognized only by their facial features or feature configuration. The images for this study are from the public internet Database of Psychology Department at Stirling University. The original face images were cropped from the hairline and under the chin, so that the part of the neck was seen. The images were stretched into 106×106 pixel squares with a gray background. Two spatially overlapping stimuli were presented in succession. First one for 40 ms and the second one for 20 ms with 0 ms interstimulus interval (40 ms SOA). After each paired exposure, six photos were shown at the center of the monitor. The task was to match faces that were shown with two of the six alternatives and to decide in which order they were presented. Under each one of the six photos there were buttons “1” and “2,” so the responses were made by clicking respective buttons on the computer monitor (Fig. 1). In the response set of six alternatives the two test pictures presented earlier were always included. The fixation point was positioned in the middle of the area where the stimuli appeared.

The exposure durations used for the first and second stimuli and the interstimulus interval were found in a preliminary study as follows: in order to find an interval where neither of the two successive visual



Fig. 1. An example of the screenshot of the stimulus alternatives presented in order to allow identification of the two successive, spatially overlapping test stimuli presented earlier.

stimuli would prevail, but each of them could be recognized with compatible, but not 100%, probability, pilot trials with variable durations of the stimuli and variable SOAs were conducted. Thus the conditions where only first or second stimuli could have been perceived were excluded. In this case a sufficient number of trials (400–2000) gives the stability and regularity to the results [Rodina et al., 2002].

Exposure Conditions

The EMF exposure conditions were the same for all subjects. During each test session, the experimenter knew the exposure condition for each subject. The exposure conditions were similar to those in previous works [Lass et al., 1999, 2001, 2002; Hinrikus et al., 2004]. Each subject had to take his or her seat behind the computer 2 min before the actual session started. It was necessary because in EMF sessions the EMF radiation was switched on 2 min before the test and subjects had to be exposed for this period. The EMF was left on until the end of the session. One test session together with pre-exposure (2 min) lasted about 5–7 min.

The 450 MHz EMF was generated by the Rhode & Swartz (Munich, Germany) signal generator model SML02. The RF signal was 100% on-off amplitude modulated by the pulse modulator SML-B3 at the

frequency of 7 Hz (duty cycle 50%). The 7 Hz frequency was chosen based on findings [Lass et al., 2001], which indicate that this modulation frequency had most remarkable effect on human EEG alpha waves. The generator signal was amplified with the Dage Corporation (Microwave Solutions Inc., National City, CA, USA) power amplifier model MSD-2597601. The 1 W EMF output power was guided by coaxial cable to the 13 cm quarter wave antenna NMT450 RA3206 by Allgon Mobile Communication AB (Akersberga, Sweden), located 10 cm from the skin of the right side of the head.

The specific absorption rate (SAR) calculation inside the brain was based on the measured field power density on the skin. The EMF was measured by the field power density meter Fieldmeter C.A 43 Chauvin Arnoux (Paris, France) and monitored during the experiments by the IC Engineering (Thousand Oaks, CA, USA) Digi Field C field strength meter. The measured field power density at the scalp was 0.16 mW/cm^2 . The SAR calculated by the formula $\text{SAR} = \sigma E^2 / 2\rho$ for brain conductivity at 450 MHz $\sigma = 1.18 \text{ S/m}$ and density $\rho = 1000 \text{ kg/m}^3$ was 0.351 W/kg . This formula considers neither the real pattern of field power density distribution inside an inhomogeneous body nor the reflection from the body surface [Hinrikus et al., 1995].

The results of numerical calculations based on the digital anatomical model took into account the frequency dependence and possible variations of tissue dielectric value and conductivity. This allowed us to obtain a more reliable estimation of the whole body and localized SAR. In our case (brain tissue, 450 MHz frequency), the normalized SAR to EMF power density (mW/cm^2) ratio factor was 0.06 (W/kg)/(mW/cm^2) [Gajšek et al., 2001]. Based on these considerations, the calculated SAR value was 0.0095 W/kg . The levels of power density and SAR calculated by both methods were so low that thermal effects are extremely unlikely.

Statistical Analysis

According to the primary criterion selected for the study—correct identification of the target and masking stimuli—the “zero hypothesis” was as follows: the number of right answers cannot be different in EMF exposed and sham conditions. In order to estimate the weight of identification and order, the analysis of the data was made in two different ways: (1) regarding correct identification of the faces and the order of their presentation and (2) regarding only correct identification of the faces irrespectively of their order.

The mean values and standard deviations of the answers were calculated for exposed and sham exposed conditions. A two-tailed Student's *t*-test was applied for statistical analysis of the numbers of right answers of the exposed and sham exposed subjects; $P < 0.05$ was considered as significantly different.

Additionally, wrong answers were grouped into seven exclusive categories in order to try to clarify their characteristics—mistakes in identification or order. The answers were grouped as follows: first correct,

second correct, both incorrect, both correct but wrong order, first correct but wrong order, second correct but wrong order, no answer. The mean values and standard deviations of the answers were calculated for exposed and sham exposed conditions for every subgroup. A two-tailed Student's *t*-test was applied for statistical analysis of the numbers of answers of the exposed and sham exposed subjects in every subgroup.

RESULTS

The results for both types of analysis—firstly, regarding correct identification of the stimuli and the order of their presentation and secondly regarding only correct identification of the stimuli irrespectively of their order—are presented in Tables 1 and 2.

According to the results of the statistical analysis presented in the Table 1, there is a rejection of the zero hypothesis. A statistically significant difference in responses from exposed and sham exposed subjects ($P < 0.05$) exists when both stimuli were recognized correctly in right order. The successful identification of both stimuli in their correct order was better with sham exposure; the actual mean difference was around 5%. It is also remarkable that the correct answers decrease in 9 out of 10 subjects under the exposure condition compared to sham. The results in Table 2 do not show that low level EMF exposure produces any significant effect on recognition of the pictures. But observing the results for the criterion of correct stimulus recognition for both of the successive stimuli, we see that the EMF effect is quite close to significant level ($P = 0.06$) and has the same trend as in Table 1; correct recognition of both stimuli is more frequent under the sham exposure conditions.

TABLE 1. Results of the Test Analyzed in Terms of Correct Identification, Including Perception of Order (Primary Criterion Bold)

Subjects	Both correct		First correct		Second correct		Both incorrect		Both correct wrong order		First correct wrong order		Second correct wrong order		No answer	
	EMF	Sham	EMF	Sham	EMF	Sham	EMF	Sham	EMF	Sham	EMF	Sham	EMF	Sham	EMF	Sham
1	9	11	48	51	57	59	141	145	16	15	60	53	62	61	7	5
2	62	65	35	36	45	35	10	9	79	93	162	148	6	14	1	0
3	35	43	58	61	51	58	48	51	53	46	117	111	38	30	0	0
4	40	34	40	33	40	35	16	18	66	81	172	177	26	20	0	2
5	62	68	116	110	25	39	8	10	69	56	67	75	50	38	3	4
6	38	40	62	77	49	40	39	37	58	61	115	104	39	41	0	0
7	60	63	104	80	39	34	23	30	51	61	70	67	53	65	0	0
8	86	90	159	164	23	23	11	16	39	35	45	36	36	36	1	0
9	47	48	58	61	46	44	47	31	67	65	102	110	31	39	2	2
10	54	62	38	23	46	54	7	11	71	80	169	156	14	14	1	0
Mean	49	52	72	70	42	42	35	36	57	59	108	104	36	36	2	1
SD	20.69	21.95	41.02	41.95	10.85	11.69	40.53	40.72	18.45	23.13	47.49	46.53	17.26	17.52	2.17	1.89
<i>P</i> -value	.04		.55		1.00		.71		.44		.15		.90		.59	

TABLE 2. Results of the Test Analyzed in Terms of Correct Identification of the Faces Irrespective of Perception of Order (Primary Criterion Bold)

Subjects	Both correct		First correct		Second correct	
	EMF	Sham	EMF	Sham	EMF	Sham
1	25	26	108	104	119	120
2	141	158	197	184	51	49
3	88	89	175	172	89	88
4	106	115	212	210	66	55
5	131	124	183	185	75	77
6	96	101	177	181	88	81
7	111	124	174	147	92	99
8	125	125	204	200	59	59
9	114	113	160	171	77	83
10	125	142	207	179	60	68
Mean	106	112	180	173	78	78
SD	32.74	35.79	30.33	29.64	20.18	21.53
P-value	.06		.15		.88	

Additional analysis for different subgroups of wrong answers shows that these answers have a different trend. We see no significant changes in these categories comparing EMF and sham. With such an experimental arrangement the most sensitive categories of answers expected to be “second correct” and “second correct wrong order,” as these should reveal the changes in visual masking most clearly. In these cases, shown in columns 3 and 7 of Table 1, EMF exposure effect on human visual perception was not detected.

DISCUSSION

Experimental results support the hypothesis of this study and the significant differences are obtained in the primary criterion—correct identification and order of two stimuli—between EMF and sham conditions. Despite this fact it is rather difficult to postulate the certain effect of the low level 7 Hz modulated EMF exposure on the functioning of the perceptual system in visual information processing. The problem is that there is still a quite high chance of the occasional artefactual significant effect. The actual mean difference in that category of answers was 3 (5%) and the probability ($P = 0.04$) is on the borderline of significance, which does not exclude the fact that possible effect could occasionally be produced by chance. The finding is weakened also by the fact that the additional analysis of characteristics of wrong answers did not show any trend of changes or significant differences between exposed and sham exposed conditions.

The obtained EMF effect appears to be on the threshold level. The weakness of the effect can be explained also by short time of the EMF exposure. In our previous study [Hinrikus et al., 2004] we mentioned

that EMF exposure effect became apparent after the third or fourth stimulation cycle.

The masking as a research method is new in the field of EMF effect studies, but the method itself is widely used in cognitive psychology and has been proved to be useful for detecting alterations in cognitive functions with different diseases as well as external physical stressors [Van Honk et al., 2002; Green et al., 2003; Kammer et al., 2003; Macchi et al., 2003]. The method can be considered as a model of the initial level of visual perception. In the visual sense, practically all kinds of memory are used: the long term memory for recognition, the short term (working) memory for responding, and the sensory memory for immediate representation. In the masking experiment the most important role is probably carried out by the sensory memory, because only two stimulus alternatives of highly overlearned stimulus-type are used, which does not exceed the working memory capacity or pose serious problems for long term memory processes. Based on that, we claim that 7 Hz modulated low level electromagnetic field has either no effect on the sensory memory functions or that this effect is too weak to be noticeable. The same applies to the capacity to switch attention between two successive, very rapidly presented target stimuli.

When comparing these findings with previous studies where a mild facilitating effect of short term visual memory was observed during EMF exposure conditions [Krause et al., 2000b; Lass et al., 2002], we see no contradiction with our current findings because the memory functions studied were probably different. In previous cases it was mainly working memory and in current case it was sensory memory.

Moreover, the present findings did not show any change in variability of responses when comparing EMF and sham conditions. The increase in the variability of errors in the exposed group was observed in an earlier study of the neuropsychological tasks, associated with attention and short term memory. It was proposed that this trend is related to individual behavior and different sensitivity to the microwave exposure of different persons [Lass et al., 2002]. Unchanged variability values in this case strengthen the assumption that very early stages of visual perception are not strongly influenced by low level EMF exposure.

CONCLUSION

The method of visual masking was applied to investigate the possible effects of low level modulated microwaves on different kinds of memories: long term, working, and sensory memory. The last of these

probably played the most important role in this experiment. The experimental data shows a mild influence of low level electromagnetic field in this aspect of visual perception.

In conclusion we can say that early stages of visual information processing are overwhelmingly robust and routine (and adaptively significant) activities, so that the physical field effects exerted upon it are extremely weak.

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