

Effects of electromagnetic field emitted by cellular phones on the EEG during a memory task

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The effects of electromagnetic fields (EMF) emitted by cellular phones on the ERD/ERS of the 4–6 Hz, 6–8 Hz, 8–10 Hz and 10–12 Hz EEG frequency bands were studied in 16 normal subjects performing an auditory memory task. All subjects performed the memory task both with and without exposure to a digital 902 MHz EMF in counterbalanced order. The exposure to EMF significantly increased EEG power in the 8–

10 Hz frequency band only. Nonetheless, the presence of EMF altered the ERD/ERS responses in all studied frequency bands as a function of time and memory task (encoding vs retrieval). Our results suggest that the exposure to EMF does not alter the resting EEG *per se* but modifies the brain responses significantly during a memory task. *NeuroReport* 11:761–764 © 2000 Lippincott Williams & Wilkins.

Key words: Alpha; EEG; EMF; ERD/ERS; GSM; Memory; Theta

INTRODUCTION

Cellular mobile phones (GSM, Global System for Mobile Communication) emit high-frequency electromagnetic fields (EMF). The close proximity of a mobile phone to the user's head leads to the absorption of a part of the EMF by the head and brain [1]. The possible effects of such fields on the human body and brain have recently been broadly discussed. Conflicting effects of EMF have been reported in the electroencephalogram (EEG). While some studies have reported that exposure to EMF around 900 MHz affects the EEG [2–4], not all studies have been able to demonstrate such effects [5,6].

EEG frequencies are traditionally subdivided into frequency bands: theta (4–8 Hz), alpha (8–12 Hz), beta (about 14–30 Hz) and gamma (around 40 Hz). The simultaneously recorded responses of different EEG frequency bands differ from each other [7–9] and reflect different cognitive and/or mental processes or states [10–14].

The aim of the present exploratory study was to assess the possible effects of EMF exposure on human brain electric oscillatory activity during cognitive processing, more specifically, during an auditory memory task with words as stimuli [13,15,16]. We focused on event-related desynchronization (ERD) and synchronization (ERS) [17] of the 4–6 Hz, 6–8 Hz, 8–10 Hz and 10–12 Hz narrow EEG

frequency bands. This experimental paradigm allowed us to examine the possible subtle effects of EMF on brain electric oscillatory activity as a function of time, memory task and hemisphere.

MATERIALS AND METHODS

Subjects: Sixteen healthy, right-handed adult volunteers (eight males; mean age 23.2 years) participated in the experiment. None of the subjects reported any hearing defects, neurological disorders, or were on medication.

Stimulus materials: The stimuli were 24 auditorily presented Finnish verbs spoken with a female voice. The mean ($\pm$ s.d.) length of the stimuli was 6.7 ± 0.9 letters and the mean duration was 764 ± 81.7 ms. The Neuroscan Stim system was used to control the presentation of the auditory stimuli. The stimuli were presented through E-A-RTONE ABR insert earphones (10 Ohm) at a comfortable sound pressure level (~ 70 dB).

A modified version of Sternberg's memory search paradigm [18] was used. A total of 192 four-verb memory sets were constructed. Each memory set consisted of four auditorily presented Finnish verbs. The frame set size was kept constant and consisted of one verb (probe). Each of the memory sets was randomly drawn from the 24 verbs,

with the restriction that each verb had to occur with equal frequency and only once in the same memory set. The stimuli were presented in 192 pseudorandomized blocks of five verbs each (memory set: four verbs; target: one verb). After 2000 ms following the presentation of the memory set, a fifth verb was presented to the subject. The subject then had to decide whether the fifth verb was among the previously presented four verbs. In 50% of the cases the probe verb was among the previously presented four-stimulus block.

EMF procedure: Each EEG registration was subdivided into two segments, one with the EMF turned off and the other with the EMF turned on. The EMF exposure order was counterbalanced across the subjects, with the EMF active in the first segment for half of the subjects, and vice versa for the other half. The presence or absence of the EMF was unnoticeable for the subjects under the investigation (single-blind condition).

A standard GSM phone was mounted to the subject's head over the right posterior temporal region, comparable to normal use, during both experimental conditions (EMF off and on). The antenna was located about 20 mm from the head. The electromagnetic field was a 902 MHz electromagnetic field pulsed with a frequency of 217 Hz and a pulse width of 0.557 ms. The mean net forward power of the aerial was 0.25 W. The phone was operated via a computer from an adjacent room with the help of an extension lead, so that the subjects were not informed about the experimental condition.

Experimental procedure: The subject was seated in a comfortable chair in a dimmed registration room and was instructed to look at a TV screen placed in front of him/her (1.5 m) and to avoid unnecessary eye movements. Each trial began with a 3500 ms intra-experimental reference (resting) condition. After this, a visual warning signal (a red spot) appeared for 100 ms on the TV screen. After 1500 ms, the four-verb memory set (memory encoding) was presented. Following an interval of 2000 ms the probe verb was presented (memory retrieval). The subject then had to decide whether the probe verb had appeared in the memory set or not. In an attempt to avoid motor artefacts, the subjects were asked to wait with their response until a visual warning signal (a green spot) appeared on the TV screen, 1500 ms after the probe. The next trial started when the subject had given his/her answer on the response pad. The length of a single trial was 16.7 s (+ response time) and there were 192 trials in all. Half of the subjects received the first 96 trials (about 30 min) while EMF was on. The order was reversed for the other half of the subjects. The total registration time was about 60 min.

Recording: Twenty Ag/AgCl electrodes (Siemens-Elema) were placed bilaterally on the subject's scalp using electrode glue and the 10/20 system of electrode placement. Additionally, two EOG electrodes were sited on the outer side of the eyes and all electrodes were referred to linked mastoids which also served as the ground electrodes. The data was recorded using a sampling rate of 200 Hz.

Raw EEG signals were recorded using the Neuroscan

386 Scan 3.0 data acquisition system with a Braintronics CNV/ISO-1032 amplifier with a frequency band of 0.3–70 Hz. The impedance of recording electrodes was monitored for each subject with a Braintronics electrode impedance meter prior to data collection and it was always below 5 k Ω .

Data processing: The digital EEG data were bandpass filtered with linear FIR (Finite Impulse Response) filters in the following four frequency bands of interest: 4–6 Hz, 6–8 Hz, 8–10 Hz and 10–12 Hz. The length of the filters was 129 points. To obtain a signal proportional to the power of the EEG frequency band, the filtered signal samples were squared. Thereafter, the data were epoched using a time window of 1600 ms. The EOG electrodes were used for artifact detection and epochs >100 μ V were rejected. The mean power in the reference interval was assigned to zero from which the relative power decrease (ERD) or increase (ERS) was calculated separately for the two experimental conditions (encoding and retrieval) and expressed as percentage.

The data were averaged over left and right electrode locations and these values were used in the statistical analyses (right hemisphere electrodes: O2, P4, T4, C4, T6, F8, F4; left hemisphere electrodes: O1, P3, T3, C3, T5, F7, F3).

Statistical analyses: The statistical analyses were conducted separately for each frequency band. The data were entered into an analysis of variance (ANOVA) with repeated measures including the following within-subject factors: EMF (two levels: on and off), time (sixteen levels: 1600 ms divided into 100 ms epochs), task (two levels: encoding and retrieval) and hemisphere (two levels: right and left).

RESULTS

The mean percentage of incorrect answers for EMF on was 5.0 ± 0.6 and 5.1 ± 0.6 for EMF off. The error rates between EMF on and off conditions did not differ statistically significantly ($F(1,15) = 0.008$, $p = 0.931$).

The results for the four frequency bands will be reported and discussed separately. Due to computational problems only 14 subjects were included in the final analyses. Only results involving the factor EMF will be discussed. Mean ERD/ERS values separately for all studied frequency bands as a function of time, task, hemisphere and EMF are displayed in Fig. 1. When appropriate, Huynh-Feldt corrected degrees of freedom and p values will be reported.

As shown in Fig. 1, no differences could be seen in the ERD/ERS responses as a function of EMF during encoding at any of the EEG frequencies. However, during retrieval clear effects of EMF were detected in all studied frequency bands especially at earlier phases (first second) of the time window. At 4–6 Hz greater ERS was found with EMF off than on, but at all higher frequency ranges (6–12 Hz) higher ERS values were observed uniformly with EMF on than off.

4–6 Hz frequency band: The main effect for the factor EMF failed to reach the level of significance $F(1,13) = 3.63$, $p = 0.0790$. The time $\times$ EMF interaction reached signifi-

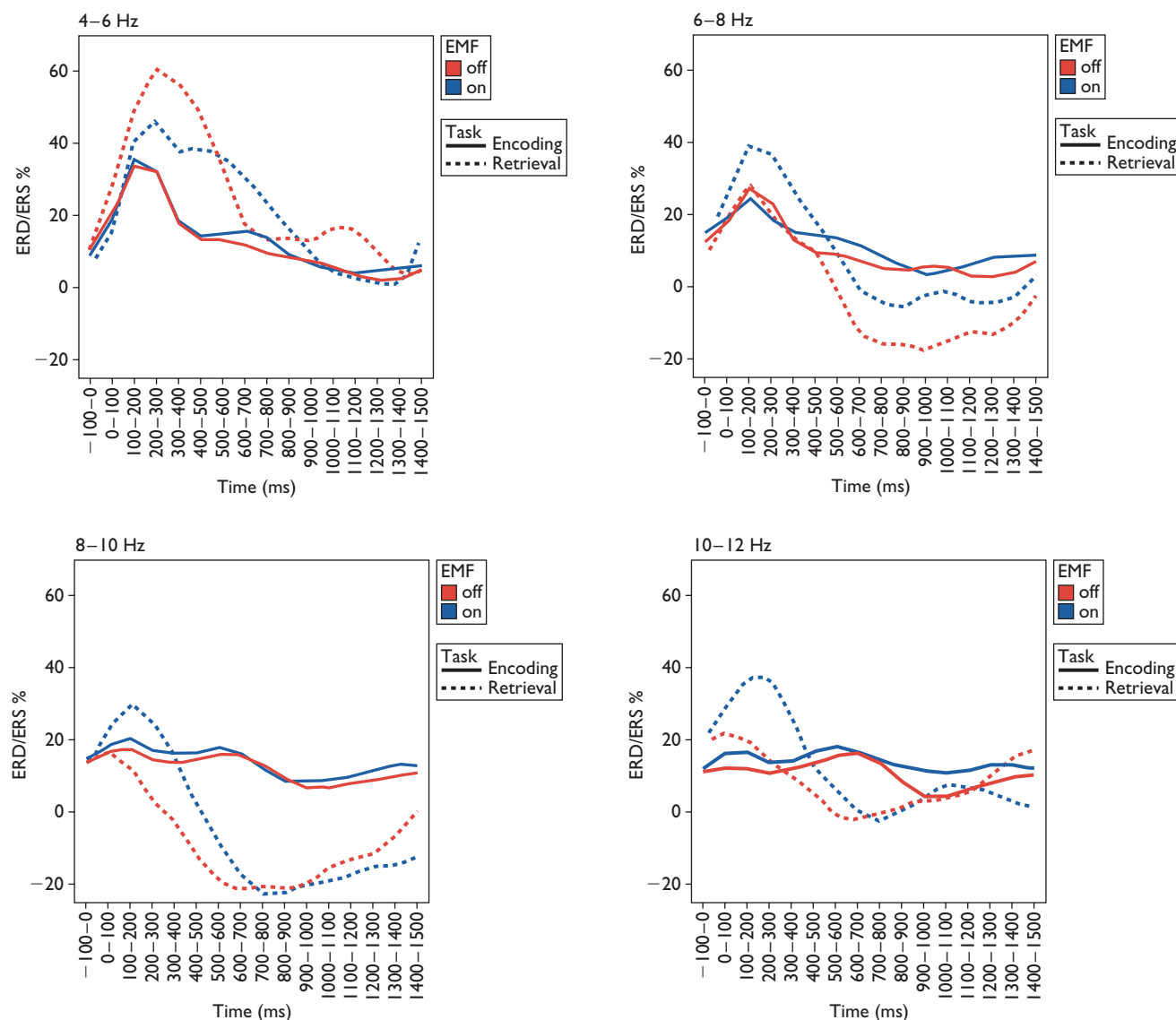


Fig. 1. Mean ERD/ERS values for the 4–6 Hz, 6–8 Hz, 8–10 Hz and 10–12 Hz frequency bands as a function of time, task (memory encoding and retrieval) and EMF (on and off). The Y-axis displays the ERD/ERS-values as percentage. Negative values indicate a relative power decrease (ERD) whereas positive values denote a relative increase in power (ERS). The X-axis depicts 16 time windows of 100 ms (–100 to 1500 ms).

cance ($F(8,103) = 4.14$, $p = 0.0003$), and it was modified by a significant time $\times$ task $\times$ EMF interaction ($F(7,94) = 2.86$, $p = 0.0088$). The exposure to EMF decreased and delayed the ERS response of this frequency band at ~ 200 – 800 ms, however, only during memory retrieval.

6–8 Hz frequency band: The main effect for the factor EMF failed to reach the level of significance ($F(1,13) = 1.89$, $p = 0.1930$). The time $\times$ EMF interaction reached significance ($F(6,73) = 5.15$, $p = 0.0003$), indicating that exposure to EMF enhanced the ERS at ~ 200 – 600 ms and decreased the ERD at ~ 600 – 1500 ms in response to auditory stimulus presentation compared with the ERD/ERS responses while EMF was off.

8–10 Hz frequency band: The main effect for EMF was significant ($F(1,13) = 6.74$, $p = 0.0221$), showing that the exposure to EMF increased the relative power in this frequency band. The time $\times$ EMF interaction reached significance ($F(4,49) = 7.57$, $p = 0.0001$) as did the time $\times$ task $\times$ EMF interaction ($F(3,40) = 3.81$, $p = 0.0167$). These results demonstrated that during memory retrieval, the exposure to EMF enhanced the ERD/ERS responses (~ 100 – 700 ms) compared with the responses elicited without exposure to EMF.

10–12 Hz frequency band: The main effect for the factor EMF was not significant ($F(1,13) = 0.26$, $p = 0.6213$). The time $\times$ EMF two-way interaction reached the level of sig-

nificance ($F(4,52)=4.59$, $p=0.0031$), as did the time $\times$ task $\times$ EMF three-way interaction ($F(6,72)=3.70$, $p=0.0037$). During memory retrieval, the exposure to EMF evoked ERS ~ 200 – 500 ms after stimulus presentation, such synchronization being absent while EMF was off.

To summarize, during memory retrieval, the exposure to EMF significantly altered the ERD/ERS responses in all frequency bands studied. No such alterations were observed during memory encoding.

DISCUSSION

In order to study the effects of EMF on brain electric activity during cognitive activity, we examined the ERD/ERS responses of several narrow EEG frequency bands while our subjects performed an auditory memory task. Our results suggest that GSM phones have effects on brain electric oscillations in the 4–12 Hz frequency band range in particular during cognitive processing.

The main effect for the factor EMF reached the level of statistical significance in the 8–10 Hz frequency band only. In this lower alpha frequency band, the exposure to EMF increased the relative power. This finding is in congruence with the results by Mann *et al.* [2], who also reported an EEG alpha enhancement induced by EMF exposure.

The exposure to EMF altered the ERD/ERS responses of different EEG frequency bands diversely as a function of time and memory task. In the 4–6 Hz frequency band the exposure to EMF decreased and delayed the early ERS response, however, during memory retrieval only. In this frequency band, synchronization represents cortical activity [12]. EMF thus decreased the magnitude of cortical activity during auditory information retrieval. In the 6–8 Hz, 8–10 Hz and 10–12 Hz frequency bands the exposure to EMF evoked increased ERS responses during the initial stages of auditory information processing and decreased the magnitude of the later ERD responses. Such alterations were most apparent during auditory memory retrieval. In the alpha frequency range, synchronization denotes cortical inactivity whereas desynchronization indicates cortical activity [12]. Also, in the alpha frequency range, the exposure to EMF appeared to decrease cortical activity during auditory information retrieval.

The ERD/ERS responses of the alpha frequency bands have been associated with attention (~ 8 Hz) and semantic memory (~ 10 Hz) functions [12]. In behavioral experiments, exposure to EMF has been reported to decrease reaction times [19,20]. The present findings could be incorporated with behavioral findings such that the pre-

sence of EMF alters the level of cortical activity applied during information processing which would be related to accelerated mental operation.

The physiological mechanisms mediating EMF effect on the ERD/ERS responses remain open: one possibility could be mild cortical temperature changes which might affect synaptic transmission [19]. Of course, the present results do not allow any conclusions concerning the possible effects of long-term cellular phone use on cognition.

CONCLUSION

We suggest that whereas the spontaneous EEG might be unaffected by EMF, the exposure to EMF has influences on neural oscillatory systems during cognitive tasks. Brain oscillatory systems associated with memory retrieval seem to be mostly affected.

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