

Gender related differences on the EEG during a simulated mobile phone signal

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The present study investigated the gender-related influence of electromagnetic fields (EMF), similar to that emitted by mobile phones, on brain activity. Ten women and nine men performed a short memory task (Wechsler test), both without (baseline) and with exposure to a 900 MHz signal. The EEG energy of the total waveform and the α , β , δ and θ rhythms were calculated from the recordings of 15 scalp electrodes. Baseline EEG energy of males

was greater than that of females, while exposure to EMF decreased EEG energy of males and increased that of females. Memory performance was invariant to EMF exposure and gender influences. These findings indicate that EMF may exert a gender-related influence on brain activity. *NeuroReport* 15:2557–2560 © 2004 Lippincott Williams & Wilkins.

Key words: Brain; Cognitive function; EEG; Gender; Mobile phone

INTRODUCTION

Wireless telephony has undergone an unprecedented expansion during the past few years. At the same time the widespread use of mobile phones raises the question of the probable hazards contingent upon their operation.

The current literature provides evidence indicating that some aspects of cognitive function and some direct measures of brain physiology may be affected by exposure to electromagnetic fields (EMF) of the type emitted by cellular telephones. Two studies published by Koivisto and colleagues showed that exposure to a 902 MHz EMF, typical of mobile telephones, decreased response times in simple reaction and vigilance tasks and the time needed to perform a mental arithmetic task [1], as well as the response times in a working memory task [2]. The same group of researchers investigating the effects of electromagnetic field exposure on electrical oscillatory activity in the human brain during an auditory memory task [3], found that exposure to the electromagnetic field increased EEG power in the 8 ± 10 Hz frequency band. However in replication studies [4], the same investigators concluded that the EMF effects on the EEG may be variable, as their previous findings were not confirmed. Roschke and Mann [5] reported no short-term effects of digital mobile radiotelephone on the spectral power density of the awake human EEG. With regards to the effects on event-related brain activity, Freude *et al.* [6] reported a decrease of human slow potentials in a visual monitoring task under electromagnetic exposure. Facilitating effects of the exposure to EMF, emitted by mobile phones, on human attention have also been reported [7,8].

As regards the gender related influence of EMF emitted by mobile phones, Smythe and Costall [9] reported sex-

dependent effects of EMF exposure on human memory. They demonstrated that males exposed to EMF during a memory task made fewer errors as compared to the performance of the same neuropsychological task without exposure to EMF. On the other hand, females were largely unaffected from EMF exposure.

At this point it should be noted that, although the digit span of the Wechsler test [10] is considered as a short-memory test, more recent reports emphasize its working memory properties, when used in conjunction with the measurement of event-related potentials. This approach may facilitate detection of electrophysiological differences of brain activity between compared groups of clinical interest at this level of analysis [11,12].

In the present paper the approach stated above was expanded to record the EEG during the anticipatory period of the Wechsler test. The main parameter under consideration was the EEG energy. Three interrelated hypotheses were studied: (a) whether healthy men and women have different EEG energy values during a working memory task, (b) whether the presence of EMF affects the EEG energy and (c) whether the EMF influence is gender-related.

SUBJECTS AND METHODS

Participants: Nineteen healthy individuals (9 men and 10 women, mean age 23.3 ± 2.23 years, mean education 16.9 ± 1.82 years) participated in the experiment. The male and female subgroups were homogeneous with regards to age and educational level. All the participants were right-handed and had no history of any hearing problem. Informed consent was obtained from all subjects.

Experimental Setup: The experimental setup included a Faraday room, which screened any electromagnetic interference that could affect the measurements. The subjects sat in an anatomical chair and a certified dipole antenna was fixed near their right ear. Care was taken to ensure that the distance between telephone and ear was constant during the whole session. The antenna was driven by a signal generator, which could be switched on or off. In the on mode the antenna emitted a 900 MHz electromagnetic field with mean power at 64 mW. The bioelectrical brain activity was recorded from fifteen scalp electrodes (Fp1, F3, C5, C3, Fp2, F4, C6, C4, O1, O2, P4, P3, Pz, Cz and Fz) according to the International 10-20 EEG system [13]. The ground electrode was positioned at the forehead.

The electrodes entered a low-pass filter placed at the boundary wall of the Faraday screen room. The filter cut frequencies >35 Hz so that the signal of the power supply network, which is at 50 Hz, would not interfere with the signal. The recording frequency was at 1 kHz. Artifact-contaminated epochs with a signal deviation >75 μ V in the EEG or 100 μ V in the EOG were excluded.

Measurements: The subjects were evaluated with the digit span Wechsler Auditory test [10]. An outline of the procedure is provided in Table 1 [11,12]. A single sound of either high (3000 Hz) or low frequency (500 Hz) was presented to the subjects through earphones, who were asked to memorize the numbers that followed. The warning stimulus lasted 100 ms. An interval of 1 s followed and then the numbers to be memorized were presented by a male voice. At the end of the number sequence presentation, the same signal tone was repeated. If the frequency of the signal tone was low, the subjects had to recall the numbers in the same order with that presented, else, if the frequency was high, the subjects had to recall the numbers in the opposite order. The signals were recorded for a 1500 ms interval, 500 ms before the warning stimulus (EEG) and 1000 ms after (ERP).

The total task consisted of 52 repetitions for a period of about 45 min. The subjects performed the tasks twice, with and without radiation, with an interval of 2 weeks between the measurements. The order in which the subject was exposed at the EMF (exposure at the first or second visit) was random.

Data transformations: In order to optimize the signal to noise ratio the grand average across the 52 repetitions for each channel of each subject was calculated. Subsequently all values were average referenced. This procedure was performed separately for the two groups and the two measurements, which correspond to the two EMF conditions. The final data for analysis for each subject and condition consisted of 1500 amplitude values for each electrode (Fig. 1a) corresponding to the 1500 ms of the time period as described above.

For each electrode, the amplitude in the frequency domain was calculated using the Fourier transform (FFT). This analysis confirmed the expected pattern of the spectral content of the signals, with the appearance of peaks within the range of the four basic rhythms δ (0–4 Hz), θ (5–7 Hz), α (8–13 Hz) and β (14–30 Hz) in all EEG series of data as shown in Fig. 1b.

The next step was the confirmation of the Parseval’s theorem in order to check the accuracy of the FFT calculations. Parseval’s theorem states that the energy of a signal at the time domain and the energy of the same signal at the frequency domain should be equal. The two spectral energies were found to be identical.

Subsequently the spectral energy was calculated in the distinct frequency bands of δ , θ , α and β for each subject and condition. It was found that on the average, the sum of the energies of the four basic rhythms amounted to 87.8% of the total EEG energy.

Statistical analysis: The distributions of the EEG energies at all electrodes both in the presence and absence of EMF did not deviate from normality. Furthermore Box’s M test confirmed that there was no departure from multivariate normality. This justified the application of multivariate tests. An experimental condition (2) $\times$ electrode (15) $\times$ gender (2) MANOVA procedure with repeated measures was applied. The presence or absence of EMF (experimental condition) was the primary within subjects factor, while the 15 electrodes were nested within each condition. The gender was the

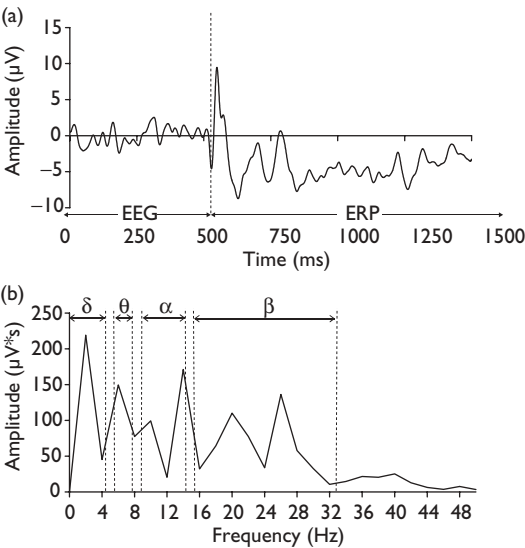


Fig. 1. (a) Representative graph of the 1500 amplitude values of the electrode Fp1 for subject #1. (b) Representative diagram of the Fourier transformed EEG values of the electrode Fp1 for subject #1.

Table 1. Outline of the experimental procedure.

Time period	Action: A-----> B-----> C-----> D-----> E-----> F-----> G
AB (500 ms)	Recording of EEGs.
BC (100 ms)	Warning stimulus (500 or 3000 Hz, 65 dB) and recording of ERPs.
CD (900 ms)	Recording of ERPs.
DE (varies) (Not in scale)	Computerized administration of the sequence of numbers of the Wechsler Direct Auditory Memory Test. The duration of this period depends on the numbers of digits to be recalled in each trial (from two to nine digits across trials). Between administered digits, the time interval is 1 s.
EF (100 ms)	Repetition of the warning stimulus.
FG (not in scale)	Recording of the memory recall performance according to the accuracy of responses (varies between 15 and 30 s)

between subjects factor. Of particular interest was not only the effect of the factors but also of their interactions, especially the condition $\times$ gender interaction. If the latter was found to be significant, then gender differences within each condition and condition differences within each gender were sought.

Initially for each subject and experimental condition both the total EEG energy and the energy of the four basic rhythms were calculated. These values served as a basis for the calculation of the differences of the corresponding energies with and without radiation (energy difference (ed)=energy_{on}–energy_{off}).

Between the two experimental conditions within each sex the number of the electrodes at which positive differences were observed (ed+) were counted. Consequently the number of electrodes at which negative differences were observed was ed–=15–ed+. Similar calculations were applied between the two sexes within each experimental condition. The resulting frequency distributions of the number of the positive and negative differences were subjected to the binomial test. The hypothesis under investigation was whether there was a concomitant pattern of electrode behavior both within sexes for each condition and within conditions for each sex.

Finally, comparisons of the mean values of memory performance of the two genders within each experimental condition were performed using the independent samples *t*-test, while comparisons of two experimental conditions within each gender were performed with the paired samples *t*-test. The significance level was set at 0.05.

RESULTS

EEG energy data: The EEG energy values (mean $\pm$ sd) for the two experimental conditions and the two genders at the fifteen electrodes were calculated. The experimental condition (2) $\times$ electrode (15) $\times$ gender (2) MANOVA procedure showed that there was a significant condition $\times$ gender interaction. (Pillai's trace=0.327, $F(1,17)=8.3$, $p<0.05$).

Figure 2a shows the average over the differences of the EEG energies between male and female subjects (EEG male–EEG female) for each experimental condition. The asterisks denote the electrodes, at which the difference between the EEG energies of the two genders is statistically significant. In the absence of EMF the EEG energy of the males is greater than the EEG energy of the females for all electrodes. Statistical significance is achieved at all electrodes except Fp1, F3 and C3. In the presence of EMF the picture is reversed i.e. the EEG energy of the males is less than the EEG energy of the females for all electrodes except Fp2 and O1, though the differences in this case do not achieve statistical significance.

Figure 2b gives another aspect of the gender and the EMF exposure interaction, as it shows the average over the differences of the energies between the two experimental conditions (EMF on–EMF off) for each gender at the 15 electrodes. The asterisks denote the electrodes at which the difference between the EMF on and EMF off condition is statistically significant. It is remarkable that the differences for the males are negative at all electrodes in contrast to the females, where the differences are positive. This means that under the influence of the radiation the spectral energy of the males' EEG is decreased while the opposite situation appears for the females. Statistically significant differences for the males were observed at eight electrodes, while for the females were observed at four electrodes.

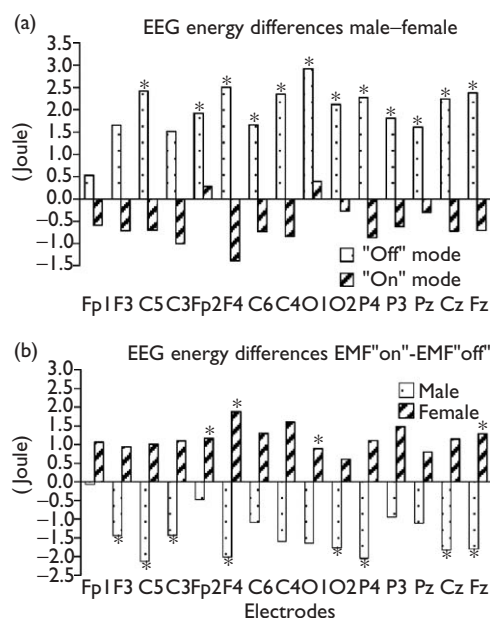


Fig. 2. (a) Average over the differences of the EEG energies between male and female subjects (Male–Female) in the presence and absence of EMF. (b) Average over the differences of the EEG energies between the two experimental conditions (EMF "on"–EMF "off") for male and female subjects.

Table 2 shows the signs of the differences of the EEG energies between the genders for each experimental condition and between the experimental conditions for each gender. The parentheses contain the number of the electrodes for which positive or negative differences were found. It seems that the findings for the total EEG energy cited above are reiterated for the energies encompassed in the four basic rhythms. The relative decrease of the EEG energy caused by the presence of EMF on the males is more notable than the corresponding relative increase on the females.

The differences were between male and female subjects for each experimental condition and between the experimental conditions for each gender, both for the total EEG energy and for the specific bands.

The gender $\times$ condition interaction is interpreted by the crossover effect of EMF on gender. This means that in the majority of electrodes in the absence of EMF the EEG energy of the males is greater than that of females while in the presence of EMF the picture is completely reversed.

Behavioral data: In the absence of EMF the memory performance of the males was 123.7 ± 46.67 and that of the females 111.1 ± 41.5 . In the presence of EMF the memory performance of the two groups was 112.4 ± 37.9 and 115.7 ± 36.4 respectively. There was no statistically significant differences in memory performance between the two conditions in either group. It should be noted that the total digits presented exceeded 298.

DISCUSSION

In the present study the EEG was recorded during the anticipatory period of the Wechsler test for 500 ms. Baseline EEG energy of males was greater than that of females, while exposure to EMF decreased EEG energy of males and increased that of females.

Table 2. Number of electrodes with positive/negative energy differences.

Difference	Radiation		Gender	
	"Off"	"On"	Male	Female
	Male–Female	Male–Female	"Off"–"On"	"Off"–"On"
Total	+(15/15)	–(13/15)	+(15/15)	–(15/15)
δ	+(15/15)	–(12/15)	+(14/15)	–(15/15)
θ	+(15/15)	–(14/15)	+(15/15)	–(15/15)
α	+(15/15)	–(11/15)	+(10/15)	–(15/15)
β	+(15/15)	–(15/15)	+(15/15)	–(15/15)

The source and functional correlates of the EEG spectral energy remain largely unknown. However, they have most often been associated with attention (alpha band), motivation (theta and delta bands), as well as vigilance (beta band) [14].

The differences between the two genders in EEG patterns obtained in EMF off condition appear to be consistent with gender differences in functional brain organization as indicated in psychophysiological and neurobiological studies [15]. Information processing appears to be different between sexes, as many studies on the performance of cognitive tasks have shown. Women are superior in perceptual speed, verbal fluency, motor coordination, and mental arithmetic, while men are superior in spatial tasks (mental rotation, spatial orientation), aim-directed motor responses, and mathematical reasoning [16,17]. These differences are probably caused not only by gender-specific education, but also by genetic differences in brain organization, which are related to different hormonal influences during ontogenetic development [18]. Functional differences extend to parameters of the spontaneous EEG [19] as well as to evoked EEG induced by tasks with particular neuropsychological meaning [20,21].

The effect of EMF exposure (reduction of spectral EEG energy for males and increase for females) may be related, both with the gender-related information processing (as mentioned above), and the nature of the interaction of EMF with biological systems. An extensive review of the effects of EMF exposure on the electrophysiological functioning of the brain can be found in Cook *et al.* [22].

In this context it is worth noting that neurophysiological studies provide evidence indicating the involvement of blood–barrier permeability in the effect of mobile phones on the brain (for a review see [23]). This is an interesting concept, in view of the fact of the existence of gender-related blood-barrier differences. Nevertheless, the complexity of research in this field, as well as the lack of a theoretical framework, leaves considerable space for speculation.

In the present study males and females showed no statistically significant differences in memory performance. This finding is in agreement with results of recent studies reporting no effect of EMF on reaction time and performance of visual working memory [24], but is in contrast with others (as mentioned earlier) reporting that exposure to EMF may have an effect upon cognition [1,2]. Further studies with more rigorous and standardized methodologies may solve these discrepancies.

CONCLUSION

The findings of this study indicate that the presence of an electromagnetic field, created by a dipole antenna emitting

at a mobile phone frequency, may affect brain activity. Interestingly this influence appears to be gender related.

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