EFFECTS OF EXPOSURE TO ELECTROMAGNETIC FIELDS OF TYPE GSM ON SLEEP EEG AND REGIONAL CEREBRAL BLOOD FLOW

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Abstract: The results of our four recent studies [1,4,5] provide consistent evidence that radio frequency electromagnetic fields (RF EMF) similar to the ones emitted by mobile phones affect brain physiology. RF EMF exposure induced reproducible changes in the nonREM sleep electroencephalogram (EEG) and altered regional cerebral blood flow (rCBF). These studies are compared and discussed.

1. Introduction

Usage of mobile phones is rapidly increasing, but there is limited data on the possible effects of RF EMF exposure on brain physiology. Given the immense number of mobile phone users, even small adverse effects could have major public health implications [19]. A recent governmental report of the UK advises exercising caution in using mobile phones, because there is a lack of scientific data on their possible health effects [7]. It is well documented that RF EMF induce heating in the irradiated tissue and adequate exposure limits were defined [6]. On the other hand, possible adverse health effects due to non-thermal interactions have not been conclusively demonstrated and the mechanisms underlying such interactions are not understood.

There is an increasing body of studies investigating biological effects of exposure to radio frequency RF EMF of the type GSM (Global System for Mobile communications) on cell cultures, animals and humans.

For example, effects of RF EMF exposure on cognitive functions have been investigated by several groups. RF radiation speeded up response times in simple reaction time tasks, vigilance and working memory tests [9,10,15]. In a working memory task, event-related desynchronization and synchronization of the waking EEG showed increased power during exposure in the 8-10 Hz [12] and 6-8 and 8-10 Hz [13] frequency range, respectively. The authors hypothesized that RF EMF exposure modulates the response of EEG oscillatory activity around 8 Hz specifically during cognitive processing [11]. In a recent study in Narcoleptics effects of RF radiation on visual event related potentials were observed and reaction times were reduced [8].

Several studies have also investigated the effects of RF EMF on human sleep. Mann et al. [14] reported a reduction of REM sleep and changes in the spectral power of the EEG in REM sleep. In two follow up studies, no effects of RF EMF on sleep and the sleep EEG were found [17,18]. In contrast, we reported that exposure to RF EMF either during sleep [1], or during waking prior to sleep [4,5] affected the nonREM sleep EEG. In the latter studies, the field conditions were well defined and dosimetry was thoroughly evaluated.

2. Methods

2.1 Intermittent nighttime exposure to RF EMF

In experiment 1 (Expt 1) [1], nocturnal sleep of 24 healthy young right-handed men was recorded during a night with exposure to intermittent "base-station-like", pulse-modulated RF EMF (see RF EMF conditions) and compared with a night of sham exposure (no RF EMF). The experiment consisted of two sessions of two consecutive nights at an interval of one week. In each session, the experimental night was preceded by a pre-experimental night. During exposure nights, RF EMF was turned on and off intermittently at 15-min intervals starting with the on-condition at lights-off. The pre-experimental night was recorded in a different room than the experimental night. Behind each bed an array of three $\lambda/2$ dipole antennas was mounted at a distance of 30 cm from the head of a recumbent subject (Fig. 1). Absorber walls were placed around the bed.

2.2 Unilateral RF EMF exposure prior to sleep

Sixteen healthy young right-handed men participated in experiment 2 (Expt 2) [4]. The subjects were exposed to "base-station-like", pulse-modulated RF EMF for 30 min prior to a 3-h morning sleep episode. The time between the end of exposure and lights-off was 10 min. To ensure a continuous daytime sleep episode, sleep in the night prior to exposure was restricted to 4 h. Subjects remained in the lab and were under constant supervision between the sleep episodes at night and in the morning. The experiment consisted of three sessions separated by one-week intervals. The three sessions involved right hemispheric exposure, left hemispheric exposure and sham exposure. During exposure the subjects sat on a chair with their heads positioned between two PVC plates to ensure a well-defined location with respect to the two planar antennas (Fig. 2).

2.3 Unilateral exposure to pulse-modulated and continuous-wave RF EMF

In experiment 3 (Expt 3) we aimed to clarify whether the modulation frequency components (2, 8, 217, 1736 Hz and higher harmonics) or the carrier frequency alone (900 MHz) may be responsible for the observed changes in the nonREM sleep EEG [5]. Sixteen healthy young right-handed men were exposed unilaterally for 30 minutes to EMF or sham exposed prior to a nighttime sleep episode. The experiment consisted of three sessions separated by a one-week interval. Two active RF EMF conditions were applied: continuous wave (no modulation) and a "handset-like" mode (see RF EMF conditions). Again, during exposure the subjects sat on a chair with their heads positioned between two plates to ensure a well-defined location with respect to the two planar antennas (Fig. 2).

2.4 Positron emission tomography (PET) study

In experiment 4 (Expt 4) [5] 16 healthy young right-handed men were exposed unilaterally for 30 min to RF EMF or sham exposed prior to PET scanning. Two active RF EMF conditions were applied: "handset-like" and "base-station-like" pulse-modulated RF EMF (see RF EMF conditions). During exposure the subjects sat on a chair with their heads positioned between two plates to ensure a well-defined location with respect to the two planar antennas (Fig. 2). Scanning was started 10 min after the end of the exposure of the left side of the head. For each scan, radio labeled water was administered. This procedure allows to determine changes in regional cerebral blood flow (rCBF). During the 1-min scanning intervals the subjects were instructed to silently count slowly from 1 to 60 to ensure similar cognitive activity in all conditions. Only the "handset-like" RF EMF and the sham condition have been analyzed so far.

2.5 RF EMF conditions

Two types of RF EMF exposure were used with a common carrier frequency of 900 MHz. A "base-station-like" signal approximating the signal emitted by a GSM base station (7 of 8 slots of the basic frame active) was applied in Expt 1, 2 and 4. In Expt 3 a "handset-like" signal, approximating the spectral content emitted by GSM mobile phones (1 of 8 slots active) was used and a non-modulated continuous-wave signal was applied as a second type of exposure. In all experiments sham exposure served as the control. The two pulse-modulated signals included the same ELF components in the demodulated signal (2, 8, 217, 1736 Hz and the corresponding harmonics). However, the spectral power of these components is considerably higher in the "handset-like" signal.

In all experiments, the spatial peak specific absorption rate (SAR) averaged over 10 g equaled 1 W/kg.

2.6 Polygraphic recordings

In all sleep episodes the electroencephlogram (EEG), electrooculogram (EOG) and submental electromyogram (EMG) were continuously recorded. Sleep stages were visually scored for 20-s epochs according to standard criteria [16]. For the EEG derivations power spectra of consecutive 20-s epochs (FFT routine, Hanning window, averages of five 4-s epochs) were computed. Visual and semi-automatic artifact removal was performed. For details see [1,4,5].

2.7 Dosimetry

A detailed dosimetry, providing estimates of the specific absorption rate (SAR) for functional sub-regions inside the brain, was conducted by simulation. The simulation platform SEMCAD (Schmid & Partner Engineering AG, Zurich, Switzerland) was employed. SEMCAD is based on the finite-difference time-domain (FDTD) method and enhanced with unique features for RF dosimetry.

The dosimetry is based on a human head model derived from the data set of the head of a healthy female subject (age 40) consisting of 121 magnetic resonance images (MRI), with a slice separation of 1 mm in the ear region and 3 mm for the rest of the head [2]. Functional sub-regions were derived from the original MRI slides. Dielectric parameters according to Gabriel [3] were applied.

3. Results

3.1 Intermittent nighttime exposure to RF EMF

To investigate whether RF EMF emitted by digital radiotelephone handsets affects the brain, healthy, young subjects were exposed during an entire nighttime sleep episode to intermittent RF EMF. Compared to a control night with sham exposure, the amount of waking after sleep onset was reduced. EEG spectral power in NREM sleep was initially increased (Fig. 3, left panel), an effect that then subsided [1]. The maximum rise occurred in the 10-11 Hz and 13.5-14 Hz bands. The increase in nonREM sleep in the 13.5-14 Hz band was already present during the first 30 min interval after lights off, i.e.

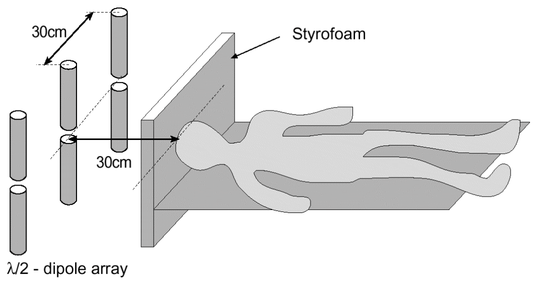

Fig. 1: Schematic diagram of the exposure setup used in experiment 1 (exposure during sleep). To expose the heads of subjects as homogeneously as possible and as independently as possible from particular sleeping postures an array of three half-wavelength dipole antennas was mounted behind the head of the recumbent subject.

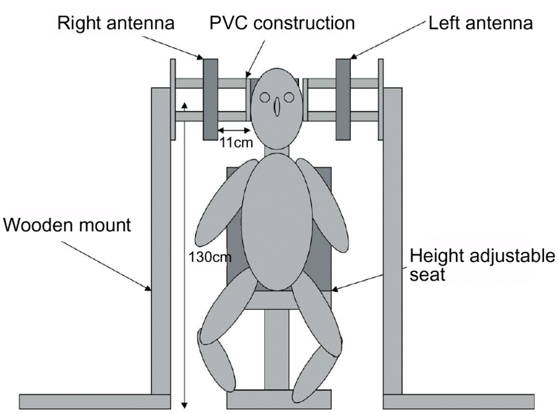

Fig. 2: Schematic diagram of the exposure setup used in experiments 2 to 4 (exposure during waking). Planar, rectangular patch antennas were mounted at both sides of the head. The position was optimized to achieve SAR uniformity of the exposed hemispheres and high average SAR ratio between the exposed and non-exposed sides of the brain.

after 15 min of EMF exposure. The results demonstrated that pulsed RF EMF in the range of radiotelephones may promote sleep and modify the sleep EEG.

3.2 Unilateral RF EMF exposure prior to sleep

Healthy, young male subjects were exposed for 30 min to RF EMF during the waking period preceding sleep. Compared to the control condition with sham exposure, spectral power of the EEG in nonREM sleep was initially increased (Fig. 3, middle panel). The maximum rise occurred in the 9.75-11.25 Hz and 12.5-13.25 Hz bands. Both hemispheres were similarly affected after left and right exposure, and thus no lateralization effect was observed. The study showed that exposure during waking may modify the EEG during subsequent sleep and that therefore the RF EMF-induced changes of brain function outlast the exposure period [4].

3.3 Unilateral exposure to pulse-modulated and continuous-wave RF EMF

We investigated whether pulse modulation of the signal is critical for the EEG effect. Nighttime sleep was polysomnographically recorded after RF EMF exposure for 30 min during the waking period preceding sleep. Pulse-modulated RF EMF enhanced power in the alpha frequency range in the waking EEG prior to sleep onset and power in the spindle frequency range during stage 2 sleep (Fig. 3, right panel). The effect was most pronounced in the second part of the night. RF EMF without pulse modulation did not enhance power in the waking or sleep EEG. The results show for the first time that pulse modulation of RF EMF is necessary to induce changes in the waking and sleep EEG [5].

3.4 Positron emission tomography (PET) study

We also addressed the question whether exposure to RF EMF modifies regional cerebral blood flow (rCBF). PET scans were taken after unilateral head exposure for 30 min. Compared to sham exposure, regional cerebral blood flow (rCBF) was increased in the dorsolateral prefrontal cortex of the exposed hemisphere after "handset-like" RF EMF exposure [5].

3.5 Dosimetry

The simulated SAR distribution revealed a similar exposure of left and right cortex (white and gray matter) and thalamus when RF EMF exposure was bilateral (Expt 1; exposure during sleep; antennas located behind the head). Unilateral exposure (Expt 2 to 4; exposure during waking) resulted in an asymmetrical exposure of the cortex (Table 1). However, left and right thalamus were similarly exposed with an estimated SAR comparable to that of the bilateral exposure.

Table 1: Estimated specific absorption rate (SAR) in left and right hemisphere. Mean (standard deviation). Cortex includes white and gray matter.

	left (W/kg)	**right** (W/kg)
Bilateral exposure		
cortex	0.17 (0.08)	0.16 (0.08)
thalamus	0.11 (0.07)	0.08 (0.04)
Unilateral exposure		
cortex	0.24 (0.18)	0.03 (0.02)
thalamus	0.13 (0.02)	0.10 (0.03)

4. Discussion and perspectives

Our studies demonstrate that RF EMF emitted by mobile phones affect brain physiology. Effects of RF EMF on the sleep EEG were observed in three studies under similar, but nevertheless significantly different conditions (exposure before sleep vs. exposure during sleep, unilateral exposure vs. exposure of the entire head, different modulation schemes).

After "base-station-like" exposure nonREM sleep EEG power was increased in the 9-14 Hz range [1,4] and the effect was observed in the early part of sleep. After "handset-like" exposure the sleep EEG was affected in the 12-14 Hz range and the effect increased in the course of sleep [5].

Changes in EEG power became rapidly evident when exposure occurred during sleep [1]. They outlasted exposure by 20-

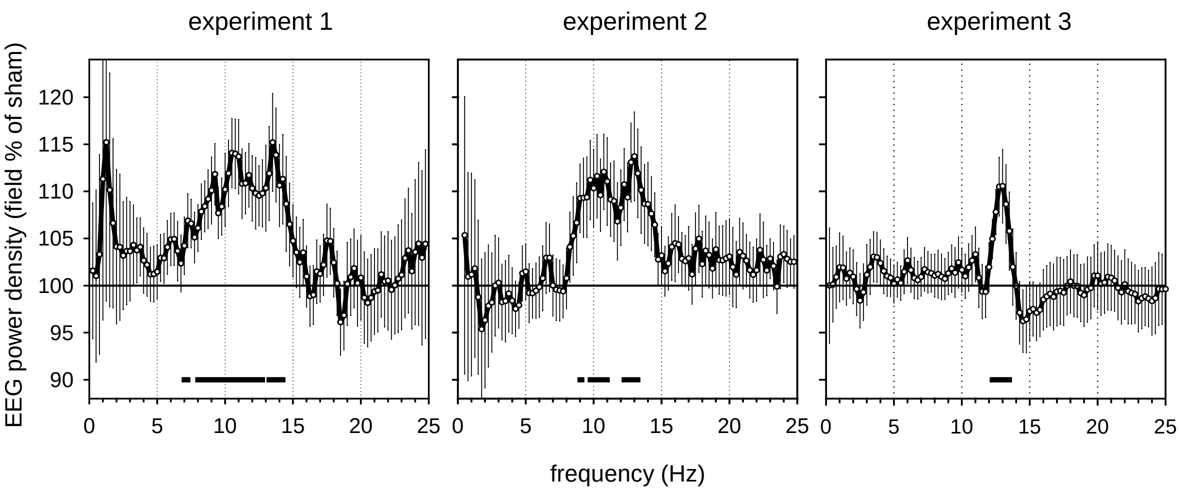

Fig. 3: Changes in sleep EEG after pulse-modulated RF EMF exposure. Mean relative EEG power density spectra in nonREM sleep. The curves represent power after exposure to pulse-modulated RF EMF expressed as a percentage of the corresponding value after sham exposure (mean ±1 SEM for 0.25 Hz bins). Experiment 1: intermitted exposure during sleep, "base-station-like" EMF; experiment 2: exposure during waking prior to daytime sleep, "base-station-like" EMF; experiment 3: exposure during waking prior to nocturnal sleep, "handset-like" EMF. Black bars at the bottom indicate significant differences (p<0.05) between RF EMF exposure and sham exposure.

50 min [4] or even hours [5] when the EMF was applied during waking prior to sleep.

Contrary to our expectation, the RF EMF induced changes in EEG power were similar in both hemispheres and no asymmetrical effects were detected [4]. One possible explanation might be that the SAR ratio between the exposed and non-exposed hemispheres was too low to induce a differential effect. Also ceiling effects cannot be excluded. In other words, even the lower field strength at the non-exposed hemisphere might have induced a maximal effect. Another explanation could be that subcortical regions such as the thalamus contain the most sensitive structures to RF EMF and that their bilateral cortical projections underlie the absence of a hemispheric asymmetry. The high levels of the estimated SAR in deeper brain structures including the thalamus are consistent with such an interpretation.

Because the time-averaged RF EMF exposure did not differ between the pulse-modulated and continuous-wave conditions, our results cannot be attributed to a thermal action of the RF radiation. The extremely low frequency (ELF) modulation components resulting from the GSM signal shape were at 2, 8, 217, 1736 Hz and higher harmonics. Therefore, a single frequency component or a mixture of components could be responsible for the observed effects. In future studies, varying the modulation characteristics of the signal will help to specify the critical frequencies. Future studies may also examine dose-response relationships by varying the specific absorption rate, which was constant at 1 W/kg in our studies.

In view of the increasing popularity of mobile phones, RF EMF effects on the brain warrant additional studies. It should be emphasized that the observed effects of pulse-modulated EMF exposure were subtle. Despite modifications of the EEG, sleep latency and the sleep stage distribution were not affected. Based on the present results it would be premature to draw conclusions about health consequences of RF EMF exposure.

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6. References

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