Bundesamt
für Strahlenschutz

Spotlight on EMF Research

Spotlight on “Impact of specific electromagnetic radiation on wakefulness in mice” by Deng et al. in Proceedings of the National Academy of Sciences (2024)

Category [radiofrequency, animal study]

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Competence Centre Electromagnetic Fields (KEMF)

1 Putting the paper into context by the BfS

Effects of exposure to radiofrequency electromagnetic fields (RF-EMF) on the human sleep electroencephalogram (EEG) have been demonstrated in several studies, but the results are still controversial. Not all studies show an effect, and the investigated parameters vary considerably between studies [2]. The study at hand [1] aims to investigate the action of RF-EMF exposure on sleep in a mouse model and addresses the influence of the carrier frequency and pulse modulation.

2 Results and conclusions from the perspective of Deng et al.

In a previous paper [3], the authors demonstrated that prolonged whole-body exposure (nine days) to 2.4 GHz RF-EMF modulated by 100 Hz rectangular pulses with a duty cycle of 1/8 resulted in increased waking time in male mice. The mice displayed a corresponding decrease in the duration of nonrapid eye movement (NREM) and rapid eye movement (REM) sleep. In contrast, prolonged exposure to unmodulated 2.4 GHz RF-EMF at the same time-averaged output power did not affect the sleep of the mice.

In this paper, the authors investigated the effect of carrier frequency (2.4 GHz and 935 MHz), pulse modulation frequency (10, 100 and 1000 Hz), pulse shape (rectangular or sinusoidal) and duty cycle (1/8 or continuous) in more detail. For the experiment, an exposure setup consisting of a metallic cage with a rectangular horn antenna that exposed the mice from above was used. The antenna was fed to achieve a time-averaged output power of 8 W, resulting in a peak output power of 64 W for the 1/8 duty cycle exposure settings. For each experiment, 12 – 19 exposed or control male mice were used. Two weeks before the experiment, four cranial EEG electrodes were implanted and electrodes for electromyography (EMG) were inserted under the trapezius muscle. The signals were recorded by a digital head stage mounted to the electrodes. The signals were spectrally analysed and classified into wakefulness, NREM and REM sleep. A baseline was recorded one day before the start of exposure, and a post-exposure recording was conducted after nine days of continuous RF-EMF exposure. The duration of each recording was twelve hours during the light phase. The duration of wakefulness, REM and NREM sleep before and after exposure was statistically analysed. Multiple testing was considered.

The experimental results as well as results from a previous study [3] of Deng et al. are depicted in table 1.

Table 1: Summary of effects of exposures to RF-EMF with a time-averaged output power of 8W on the sleep phase duration of male mice as reported by Deng et al. 2024 [1]. „–“: no statistically significant effect; „↑”: a statistically significant increase; „↓“: a statistically significant decrease in any of the three statistical analyses of the respective parameter performed by the authors. Results presented in grey were obtained in a previous study [3].

Carrier frequency [GHz]	Duty cycle	Modulation frequency [Hz]	Modulation pulse shape	Effect on wakefulness	Effect on REM sleep	Effect on NREM sleep
2.4	1/8	10	rectangular	–	–	–
2.4	1/8	100	rectangular	↑	↓	↓
2.4	1/8	1000	rectangular	↑	↓	↓
2.4	1/8	100	sinusoidal	↑	↓	↓
2.4	none	100	sinusoidal	–	–	–
0.935	1/8	10	rectangular	–	↓	–
0.935	1/8	100	rectangular	–	↓	–
0.935	1/8	1000	rectangular	–	↓	–
0.935	1/8	100	sinusoidal	↑	–	–
0.935	none	100	sinusoidal	↑	↓	–

The authors summarise that the increase in wakefulness and the decrease in sleep duration after RF-EMF exposure in mice depend on the carrier frequency and modulation frequency. Only for the carrier frequency of 2.4 GHz consistent effects (i.e. a statistically significantly increased wakefulness with statistically significantly reduced REM and NREM sleep duration upon exposure) were observed, with these effects only being present for modulation frequencies exceeding 10 Hz and with intermittent exposure (duty cycle 1/8). From that data, the authors conclude that the modulation modes of rectangular and sinusoidal pulses both induce similar effects, but the duty cycle is important for inducing effects.

Based on an estimated local specific absorption rate (SAR) of about 3 W/kg and in comparison to published studies on computer models of the human head [4], the authors conclude that the observed effects were not thermal, i.e. without a significant heating of the body tissue of the mice. From the observation that in many cases, the effect sizes were smaller and not consistent at 935 MHz compared to the ones of the same exposure scheme at 2.4 GHz, the authors speculate that the sensing of RF-EMF may require a specialised structure in living organisms.

3 Comments by the BfS

Concerning the EEG recordings in free moving mice, the study is technically well performed. However, there are methodological shortcomings which may reduce the reliability of the results.

It remains unclear whether the allocation of mice to experimental and control groups was randomised and if the study was conducted under blind conditions. However, no difference between groups at baseline was observed and in the previous study [3] the automatic classification of the EEG spectra was verified in a blinded manner. The authors state that the control animals were treated in the same way as the exposed animals, but it is not described whether these were sham controls placed in the exposure apparatus with RF-EMF turned off for nine days, or if they were kept as cage controls at the same temperature and light regime as the exposed animals.

The authors applied an exposure apparatus that was used and described in the previous study [3]. However, the given details are not sufficient to independently reproduce the experiments. Further, it remains unclear to which level the animals were actually exposed. There are indications, that the mice were kept in the reactive near field of a horn antenna which in combination with the metallic cage likely results in very

inhomogeneous exposure which complicates reliable control and assessment of the actual exposure level. This scenario poses difficulties to ensure consistent well-defined experimental conditions.

The SAR values provided were determined using the cSAR3D [5] testing system, which is much larger than the actual exposure chamber for the mice. It is therefore very likely that a spatial arrangement used to determine the SAR did not correspond to the actual exposure situation of the mice. Further, this testing system cannot be used to assess the SAR in mice because it uses phantom models designed to simulate the geometry of human body parts (such as the human head). The whole-body absorption efficiency of mice is drastically different from local absorptions in humans and depends strongly on frequency, with a maximum close to 2000 MHz. This could be an alternative explanation for the more pronounced changes observed at an exposure frequency of 2.4 GHz compared to 900 MHz. Consequently, the reported SAR values very probably do not represent the actual exposure of the mice and in contrast to the authors' assessment, thermally effects mediated by tissue heating cannot be ruled out.

Despite the methodical shortcomings and irrespective of the possible mechanisms, the study consistently shows an effect of pulse-modulated RF-EMF on wakefulness and sleep in mice. It has not been investigated if the reduction in sleep duration has any behavioural or health consequences in mice. In humans, the effects of RF-EMF exposure on sleep observed so far in experimental studies have not affected sleep quality [6]. The results presented may help to explain how certain parameters of RF-EMF exposure affect sleep, but because there are known differences in sleep and temperature regulation between rodents and humans [7] they are difficult to interpret.

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Impressum

Bundesamt für Strahlenschutz
Postfach 10 01 49
38201 Salzgitter

Tel.: +49 30 18333-0
Fax: +49 30 18333-1885
E-Mail: spotlight@bfs.de
De-Mail: epost@bfs.de-mail.de

www.bfs.de

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