

Summaries and assessments of selected studies

In the period from mid of July to beginning of November 2023, 103 new publications have been identified, and eight of these were discussed in depth by BERENIS. Based on the selection criteria, four of these publications were selected as the most relevant ones. Their summaries and assessments are provided below.

1) *Experimental animal and cell studies*

Changes in behavioral learning and profiles of serum proteins in extracellular vesicles (exosomes) of rats after simultaneous exposure to 1.5 GHz and 4.3 GHz microwaves (Wang et al. 2022)

In the *in vivo* study with rats by Wang *et al.* (2022), the influence of short-term 1.5 and 4.3 GHz microwave exposure (alone or combined; 3.3, 2.5, and 5.8 W/kg SAR for 6 minutes) on learning parameters and on the number of extracellular vesicles (exosomes) in the serum and their protein composition was investigated. A key experiment of this study involved a hypothesis-free quantitative comparison of proteins ("proteomics") contained in the exosomes. Furthermore, functional aspects of learning and memory, neuronal electrical activity and structural changes (by electron microscopy) of the hippocampus were investigated. The results showed that learning and memory performance were impaired (in the range of 10-30%) after RF-EMF exposure, especially for the combined exposure at 1.5 and 4.3 GHz frequency. In addition, the ultrastructure of the hippocampus was injured and the electrical activity (EEG) was altered. Electron microscopic analyses indicate an impairment in release of synaptic vesicles and thus altered signal transmission. Impairment was more pronounced for simultaneous exposure to both frequencies. The proteomics analyses identified proteins (VAMP8, Syn7, and VMAT) that could be involved in the perceptual impairments caused by microwave exposure. These proteins are involved, for example, in protein transport, protein localization to the plasma membrane, the regulation of endocytosis, and also in the removal of α -synuclein, a protein reported to be increased in the brain of persons with Alzheimer's disease.

The extensive study by Wang *et al.* (2022) contains functional, morphological and mechanistic data that show the observed changes in learning in connection with altered synaptic activity and morphological changes in the hippocampus. The observed impairment of learning and memory function could therefore be explained by an impairment of synaptic activity by certain proteins after short-term RF-EMF exposure.

5G-modulated radiofrequency electromagnetic fields and neuronal activity (Canovi et al. 2023)

Using a novel experimental approach, Canovi *et al.* (2023) investigated the effect of a 3.5 GHz RF-EMF (carrier wave and 5G modulation with FDD) on neuronal activity. Neurons from the cerebral cortex of rats were cultivated on chips to perform multi-electrode arrays (MEA), to analyze propagation of electrical activity in a neuronal network. In particular, spontaneous electrophysiological activity of individual cells as well as coordinated signal transmissions between neurons can be monitored over time. The authors compared parameters of neuronal activity in time windows of 15 minutes before, during and after RF-EMF exposure. No statistically significant changes in neuronal activity were found in the range of the regulatory limits (1 and 3 W/kg SAR) during exposure to both the 3.5 GHz carrier frequency or a 5G-modulated signal. However, compared to sham exposed cells, a trend towards an increased activity (mean bursting rate and spontaneous firing rate) was observed after exposure, especially for the 5G signal. In contrast, a temporary and significant decrease in neuronal network

activity was observed in the experiments with the high exposure level (28 W/kg SAR). The effect strength was similar regardless of whether a 5G-modulated signal or a carrier wave RF-EMF of 3.5 GHz or 1.8 GHz was applied. Because the temperature of the culture media increases by approximately 1°C at this exposure level, the findings were compared with a matching temperature increase in the absence of RF-EMF. Again, the researchers found a decrease in neuronal activity during the phase of temperature increase, but they noted that this effect on neuronal activity was less pronounced and could only partially explain the observations with RF-EMF exposure.

In this context, it remains uncertain whether the different dynamics of the temperature increase or a temperature gradient caused by the mode of heat input could play a role. The study by Canovi *et al.* (2023) used a state-of-the-art and a not yet widely used model system to investigate the influence of 3.5 GHz RF-EMF on neuronal activity. Effects on neuronal activity were only reported when the exposure was accompanied by an increase in temperature. Yet, it should be noted that in this study, the authors did not compare and statistically analyze the effects of sham- and RF-EMF-exposed cell cultures as mostly done, but rather relative changes over time. Choosing this approach could be due to the presumably strong variation in the basal activities of the established neural networks on the MEAs. The findings should therefore be confirmed in future independent studies, considering the uncertainty factors mentioned above.

2) Epidemiological studies

Mobile phone use and semen quality in Swiss military recruits (Rahban et al. 2023)

This cross-sectional study investigated the association between self-reported mobile phone use and semen quality in 2886 Swiss military recruits aged 18-22. Semen quality was measured as volume, concentration, total sperm count, motility and morphology. Among 20 investigated associations with categorical exposure assessment, three were found to be significant. A lower total sperm count was found in men who used their phones more than 20 times per day, compared to men who used their phones 1-5 times per day. A significantly higher percentage of sperm with a normal shape was found in men who used their phones 10-20 or more than 20 times per day. Among the five investigated associations with continuous exposure assessment, two adverse effects (on sperm concentration and total sperm count) were found to be significant. The position in which the men carried their phones when not using them (trouser/jacket pocket, bag, etc.) was not related to semen quality.

Strengths of this study include the careful assessment of sperm quality and the relatively large number of participating men, which is representative for 97% of the population of young Swiss men. This study setup is evidently better than most previous studies on semen quality, which recruited from fertility clinics and are thus typically less representative, and often biased since men are more likely to report high exposure if they think this may be connected to their fertility condition. Another strength of this study is that the exposure was assessed before the participants knew the results of their sperm analysis. Nevertheless, this is a cross-sectional study and cannot confirm causality. While results are compatible with chance findings (for example, 3 out of 20 analyzed associations were significant, and both adverse and protective effects were found), the authors emphasize significant adverse associations in the conclusions and causality is occasionally implied. Exposure was assessed based on self-reported data on mobile phone use. Yet, it is not known to what extent frequency of phone use is a proxy for the actual RF-EMF dose. Frequent phone use may theoretically be a proxy for another factor that is unrelated to RF-EMF and not taken into account, but which in turn is related to sperm quality. The definition of exposure as a self-estimated frequency of mobile phone use per day on a categorical scale is vague. As the authors acknowledge, participants' understanding of mobile phone use frequency may also have changed over the course of the study: while people used their mobile phones

relatively infrequently and mainly for calls in the earlier years (2005-2007), frequent, screen-based use became more typical in the later years (2012-2018). A follow-up study with improved exposure assessment was launched at the end of 2022. More information on this follow-up study can be found on the FOEN website (in German and French).¹

The authors interpret the trend towards a decrease in the correlation between RF-EMF and semen quality over the years as a causal trend, and attribute it to the transition from 2G to 3G to 4G technology, but no justification is given for this. The group that used their phones frequently, reported a typically less healthy lifestyle than the group who used their phones less frequently (e.g. smoking, higher alcohol and medication consumption, higher BMI, lower education). This suggests that lifestyle plays an important role, and while the analyses accounted for this in a myriad of different ways, confounding by factors not taken into account may be an issue.

3) Human experimental studies

Effect of 5G radiation (3.5 GHz) on brain activity in healthy volunteers (Jamal et al. 2023)

Thirty-four healthy volunteers (17 men, 17 women) were exposed to a 5G signal (horn antenna, 3.5 GHz, pulse-modulated (577 µs/4.6 ms), 2 V/m RMS field strength at the head) or sham exposed. Brain activity (EEG, 64 channels) was measured in the awake state (eyes open and eyes closed). In addition, heart activity (ECG) and temperature were measured and saliva samples were taken. A pre-exposure phase (baseline), the exposure phase and a post-exposure phase were recorded. Only the brain waves were analyzed in this publication. There was no effect of 5G radiation with a field strength of 2 V/m on brain activity neither during or after exposure.

It is possible that the 64 electrodes had a shielding effect and thus reduced the exposure. However, the field level was low (SAR 0.037 mW/kg, base station) and hardly any effects are to be expected at these intensities. EEG changes have so far been observed at significantly higher intensities corresponding to those of mobile phones with a SAR of around 1 W/kg.

4) Further information

Monitoring of non-ionising radiation Switzerland

The SwissNIS project consortium has published its second annual report (in German). The report describes the measurements carried out as part of the Swiss exposure monitoring programme with regard to non-ionising radiation in 2022.²

WHO reviews

A series of systematic reviews regarding health effects of RF-EMF exposure are currently being carried out on behalf of the WHO. The corresponding protocols were published in 2021 and 2022. In the meantime, the results of the majority of the reviews have also been published (Cordelli *et al.* 2023,

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<https://www.bafu.admin.ch/bafu/de/home/themen/elektrosmog/fachinformationen/forschung.html#1946991052>

² SwissNIS (2023): Expositionsmessungen nichtionisierende Strahlung: Jahresbericht 2022 - Projektkonsortium SwissNIS. 30. August 2023. Bundesamt für Umwelt (BAFU).

<https://www.news.admin.ch/news/message/attachments/82513.pdf>

Röösli *et al.* 2024, Cordelli *et al.* 2024, Bosch-Capblanch *et al.* 2024, Benke *et al.* 2024, Kenny *et al.* 2024, Johnson *et al.* 2024).³

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Additional information:

[BERENIS](#)

[List of abbreviations](#)

³ <https://www.sciencedirect.com/journal/environment-international/special-issue/109J1SL7CXT>