Bundesamt
für Strahlenschutz

Spotlight on EMF Research

Spotlight on “The effect of mobile phone electromagnetic fields on the human resting state wake EEG and event-related potential: A systematic review and meta-analysis” by Prins et al. in Bioelectromagnetics (2025)

Category [radiofrequency, review]

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Competence Centre for Electromagnetic Fields (KEMF)

1 Putting the paper into context by the BfS

The human brain is potentially exposed to radiofrequency electromagnetic fields (RF-EMF) to a relevant extent when a mobile phone is operated close to the head. Therefore, possible effects of RF-EMF on various aspects of brain function have been discussed for many years.

The World Health Organization (WHO) launched an international project to systematically assess the potential health effects of exposure to RF-EMF. Within this project, the WHO commissioned a systematic review that assessed the effects of RF-EMF exposure on cognitive functions in human experimental studies [2] (see Spotlight - Jan/2025 no.1 [3]). However, this systematic review did not consider effects on the human electroencephalogram (EEG). The present study [1] closes this gap and complements the systematic reviews commissioned by the WHO.

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

The systematic review at hand [1] aimed to assess the impact of exposure to RF-EMF similar to those emitted by mobile phones on the resting state wake EEG and on event-related potentials (ERP), i.e., brain potentials evoked by, e.g., auditory or visual stimulation, as reported in human experimental studies.

Prins et al. applied a literature search and selection strategy that followed the PRISMA Statement for reporting systematic reviews [4]. Three databases (PubMed, Embase, EMF-Portal) were searched. Eligible publications in peer-reviewed journals in English language were included. Studies focusing on resting state wake EEG and/or ERP performed in healthy adult humans exposed to RF-EMF in the frequency range operated by mobile phones were considered eligible. Only studies using a randomised controlled experimental design with at least single-blind conditions, and providing sufficient information about exposure, e.g., at least stating body-external exposure metrics, were included.

Altogether, 170 unique studies were identified in the literature search, and 51 studies published between 1995 and 2023 were finally included in the systematic review. 31 studies (corresponding to 29 trials, as two pairs of studies investigated the same set of participants and were grouped together) focused on resting state wake EEG and 20 studies focused on ERP. For twelve of these studies, suitable quantitative data were available, and they could be included in meta-analyses – seven for resting state wake EEG and five for ERP. The majority of studies investigated the impact of RF-EMF exposure with modulation characteristics similar to those of the second generation of mobile communications (2G) at a frequency around 900 MHz. The sample size varied between 10 and 120 participants. ERP were recorded during various cognitive tasks, including visual and auditory discrimination tasks.

To assess risk of bias (RoB), the Cochrane RoB tool 2.0 developed for randomised crossover trials was used [5]. Six domains of RoB were assessed: the randomisation process, period and carryover effects, deviations from the intended interventions, missing outcome data, measurement of the outcome, and selection of the reported results. Finally, the overall RoB was determined, and the studies were graded as “low RoB”, “moderate RoB – some concern” or “high RoB”. None of the included trials were rated to have a low overall RoB. For 22 of the resting state EEG trials there was some concern and seven were rated to have a high overall RoB. For twelve of the ERP trials there was some concern and eight were rated to have a high overall RoB. Main sources of RoB were the randomisation process, period and carryover effects and selective reporting. A carryover effect occurs when a possible effect of exposure persists after the end of the exposure and may affect the participant’s reaction in the subsequent session. The time needed for the carryover effect to disappear is the washout period.

Random-effects meta-analyses were performed for the endpoints power in the alpha frequency band (8.5 — 12.5 Hz) of the resting state wake EEG and ERP during different discrimination tasks. The latency and amplitude of the event related potentials P300 and P100, describing the brain response to visual stimulation, and the latency and amplitude of the event related potentials P300 and N100, reflecting auditory stimulation, were included in meta-analyses. The results of the meta-analyses are summarised in Table 1.

Exposure - Outcome	No. of studies (No. of data sets)	Sample size	RoB: No. of studies	SMD [95% CI]
Alpha power of resting state wake EEG (μV^2)				
2G - Eyes open	5 (6)*	322	Moderate: 5	0,16 [0,01; 0,32]
2G - Eyes closed	3 (3)	81	Moderate: 2, High: 1	-0,04 [-0,35; 0,27]
3G - Eyes open	1 (2)*	62	Moderate: 1	-0,16 [-0,51; 0,20]
Event-related potentials in visual discrimination tasks				
2G -P300 Latency (ms)	2 (2)	156	Moderate: 2	0,12 [-0,10; 0,34]
2G - P300 Amplitude (µV)	2 (2)	156	Moderate: 2	-0,08 [-0,31; 0,14]
2G - P100 Latency (ms)	2 (2)	156	Moderate: 2	-0,01 [-0,23; 0,21]
2G - P100 Amplitude (µV)	2 (2)	156	Moderate: 2	-0,05 [-0,28; 0,17]
Event-related potentials in auditory discrimination tasks				
2G -P300 Latency (ms)	4 (5)*	209	Moderate: 3, High: 1	0,20 [-0,14; 0,55]
2G - P300 Amplitude (µV)	3 (4)*	197	Moderate: 3	-0,05 [-0,25; 0,15]
2G - N100 Latency (ms)	3 (4)*	194	Moderate: 2, High: 1	-0,06 [-0,44; 0,33]
2G - N100 Amplitude (µV)	3 (4)*	194	Moderate: 2, High: 1	0,01 [-0,28; 0,29]
3G - P300 Latency (ms)	2 (3)	77	Moderate: 2	0,09 [-0,22; 0,41]
3G - P300 Amplitude (µV)	2 (3)	77	Moderate: 2	-0,11 [-0,43; 0,20]

Abbreviations: SMD = Standardised Mean Difference, CI = Confidence Interval, RoB = Risk of Bias.

* Note that two of the studies each contributed two data sets (young adults and elderly subgroups) to the meta-analyses.

Table 1: Summary of results of meta-analyses by Prins et al.

The power of the alpha frequency band of resting state wake EEG with eyes open was statistically significantly ($p = 0.04$) increased during 2G-like exposure in comparison to sham exposure. No statistically significant difference was found in this regard in meta-analyses with eyes closed during 2G-like exposure and with eyes open during 3G-like exposure. The increase in alpha activity of resting state wake EEG during RF-EMF exposure was observed in further studies, covering various RF-EMF frequencies. These studies were part of the systematic review, but were not included in the meta-analyses. Prins et al. conclude that there is evidence of an effect of 2G-like exposure on the resting state wake EEG under the eyes-open condition.

There was no statistically significant effect of mobile phone-like exposure on any of the analysed parameters of ERP during visual and auditory discrimination tasks.

3 Comments by the BfS

The PRISMA guidelines [4] state that registration of the review protocol prior to conducting the review aims to reduce bias, increase transparency, facilitate scrutiny and improve the trustworthiness of systematic reviews. In the present publication [1], there is no information about a registration or a published protocol. However, the published study itself provides a sufficient description of the review objectives, methods and rationale to evaluate the validity of the approach.

The assessment of RoB is well described. Prins at al. decided to assess the RoB from carryover effects as "moderate risk, i.e., some concerns" instead of "high risk" if the time between experimental sessions was less than 24 hours. They argue that the mechanisms of carryover effects are poorly understood, and that they can be considered in data analyses to avoid misinterpretation. However, it remains unclear whether this was accounted for in the data analysis of all studies with washout periods shorter than 24 hours. The mechanism behind carryover effects is indeed poorly understood, but a short break between the sessions is apparently not sufficient to let them disappear [6]. Therefore, to minimise the impact of a possible carryover effect in studies on sleep EEG [7] or cognitive function [8], a washout period of at least 24 hours is recommended. It is reasonable to apply the same rules to wake EEG studies. Therefore, the RoB for carryover effects was possibly underestimated by Prins et al.

As stated in their paper, Prins et al. were not able to assess the quality of the EEG processing and exposure setup. This is a major limitation, because possible bias due to these technical factors may remain unrecognised. Additionally, although participants' awareness of exposure status was evaluated during the RoB assessment, the lack of evaluation of the exposure setup introduces another potential source of bias. This is because the effectiveness of blinding measures to prevent possible sensory perception of exposure, e.g., due to perception of noise or warmth, could also not be assessed. Additionally, a possible publication bias was not considered.

To correctly interpret the results of a systematic review, it is important to assess the certainty of evidence of the findings, e.g., by applying the "Grading of Recommendations Assessment, Development, and Evaluation" approach [9]. Such an evaluation was not performed by Prins et al., therefore, it is difficult to state how reliable the results are.

Prins et al. did not find any effects of RF-RMF exposure on ERP recorded during cognitive tasks. This is in accordance with the results of a systematic review of Pophof et al. on the effects of RF-EMF exposure on human cognitive function [2] which included 14 of the studies on ERP that were also included by Prins et al. Pophof et al. conclude that there is mostly moderate to high certainty of evidence that short-term RF-EMF exposure at SAR levels within the recommended limits [10] does not negatively affect the investigated domains of cognitive function.

Expert committees have previously assessed the evidence for effects of RF-EMF exposure on brain function: The German Commission on Radiological Protection states that there is restricted evidence for the effects of RF-EMF exposure on wake EEG and restricted to insufficient evidence for effects on ERP [11]. The Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) concludes that the EEG variations observed under RF-EMF exposure may represent biological effects, but do not indicate any adverse health effects [12]. The present study by Prins et al. [1] systematically summarises the current knowledge on the effects of RF-EMF on wake EEG. Their result of possible effects on wake EEG is in line with the above statements, but needs to be substantiated by further high-quality studies.

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