



Bundesamt
für Strahlenschutz

Spotlight on EMF Research

Spotlight on “Characterization of the core temperature response of free-moving rats to 1.95 GHz electromagnetic fields” by Bala et al. in Bioelectromagnetics (2025)

Category [radiofrequency, animal study]

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Competence Centre for Electromagnetic Fields (KEMF)

1 Putting the paper into context by the BfS

Currently recommended radiofrequency electromagnetic field (RF-EMF) exposure restrictions are designed to prevent core body temperature (CBT) elevations of more than 1°C [2], as higher increases in CBT may lead to adverse health effects [3, 4]. Possible 'non-thermal' biological effects from RF-EMF exposures at levels below this threshold have been studied for decades. Such studies must ensure that the exposure does not meaningfully raise the test organisms' temperature.

In this *Spotlight on EMF Research* article, while focusing on Bala et al. [1], we discuss three papers that aspire to accurately and reliably measure CBT during RF-EMF exposures in laboratory animals [1, 5, 6]. The presented approach is essential for further research to differentiate between thermal and potential non-thermal effects of RF-EMF exposures.

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

The present publication on rats [1] is considered in context with an equivalent study on mice [5] and a technical description of a reverberation chamber for RF-EMF exposures [6]. Bala et al. first highlight the common fallacies in core body temperature (CBT) assessments in studies on RF-EMF exposures in rodents. CBT is often measured by rectal thermometry shortly before and after, but not during RF-EMF exposure. This process requires restraining and handling of the animals, causing stress and CBT changes that are unrelated to the exposure. To eliminate this potential source of error, implantable devices can be used to measure body-internal temperatures during exposure sessions and transmit the recorded data telemetrically. As these devices have to be surgically implanted in the body of the animals, it is important to allow sufficient recovery time between surgery and the experiments. Lastly, transport of the animals to the exposure site is another source of stress that may increase CBT and must be adequately accounted for.

Bearing these potential pitfalls in mind, Bala et al. [1] and Sylvester et al. [5] aimed to assess the CBT of freely moving rats and mice, respectively, in the absence of investigator interference and in real-time during whole-body exposures to RF-EMF at a frequency of 1.95 GHz. To this end, twelve male and twelve female animals of each species underwent surgery and commercially available radiotelemetric temperature capsules (AniPill) were implanted in their abdomen. The rats were a few weeks old, the mice were nine months old. The rodents were allowed to recover from the surgery for about two weeks before the experiments. To validate the AniPill measurement method, CBT data recorded by the temperature capsule were compared with concurrent measurements taken by rectal thermometry in mice [5]. The two methods were in good agreement.

A reverberation chamber [6] was utilised for the exposure of the rodents. Within a predefined working volume of this chamber, freely moving rodents can be simultaneously exposed to a statistically uniform RF-EMF at a frequency of 1.95 GHz. During the exposure, the ambient temperature in the chamber is maintained at 22°C, which also applies to the housing where the rodents are kept beforehand [5]. A 'power function', which takes into account the age-dependent total mass of all exposed rodents, was derived to enable the operator to calculate the chamber's input power required to achieve the desired whole-body average specific absorption rate (wbSAR). The uncertainties (corresponding to a confidence interval of 95%) for the wbSAR, arising from measurement and simulation uncertainties, were estimated to be 3.86 dB for rats and 3.89 dB for mice. These values are in the range of the uncertainties of comparable reverberation chambers [6]. In preliminary experiments with rodents and phantoms, it was also determined that the performance of the AniPill temperature measurement is not directly affected by the RF-EMF, leading to undistorted and smooth temperature measurements.

The temperature capsule recorded data every two minutes. During transport to the reverberation chamber and transfer to the exposure cages, CBT increased by 1°C in rats and up to 3°C in mice. Therefore, the animals were allowed to acclimatise for about one hour until their CBT returned to the normal range. Only then was the RF-EMF exposure started and temperature data were recorded up to one hour after the end of the exposure to fully assess the thermoregulatory response of the rodents. Rats were exposed for three

hours to an RF-EMF resulting in wbSAR values of 0 (sham exposure), 0.1, 0.4, and 4 W/kg, whereas mice were exposed for two hours to an RF-EMF resulting in wbSAR values of 0 (sham exposure), 1.25, 2.5, 3.75, and 5 W/kg. For comparison, animal phantoms carrying temperature capsules were also placed in the reverberation chamber during each exposure session.

Temperature in the phantoms increased by approximately 3°C by the end of the exposure at the highest wbSAR level. Mice showed a statistically significant increase in CBT during the first 16 minutes of exposure to wbSAR levels of 2.5, 3.75 and 5 W/kg (by 0.32, 0.24 and 0.37°C, respectively) compared to sham-exposed mice. This effect was transient. However, by the end of the exposure the average CBT of mice in the 5 W/kg group was statistically significantly higher by 0.34°C compared to sham-exposed mice.

In rats, only animals in the 4 W/kg exposure group showed an initial statistically significant increase in CBT by 0.49°C compared with sham-exposed rats. The CBT of rats in the 4 W/kg group remained elevated at a plateau level throughout the exposure period and was 0.62°C higher than in the sham group at the end of the exposure. The CBT of rats in the 0.4 W/kg group was statistically significantly higher by 0.14°C than that of sham-exposed rats at the end of the exposure. After cessation of exposure, the CBT of rats in the 4 W/kg group reached the CBT of the sham-exposed group after about one hour. The temperature drop rate was 0.016°C/min in the first ten minutes after cessation of the exposure.

Sylvester et al. conclude that, compared to animal phantoms, mice can effectively compensate for the increased thermal load due to RF-EMF exposures at the applied wbSAR levels of up to 5 W/kg. This is likely due to the engagement of thermoregulatory mechanisms. Bala et al. conclude that rats can also effectively compensate for the additional thermal load due to the applied RF-EMF exposures of up to 4 W/kg, albeit less efficiently than mice, probably due to the smaller surface-to-mass ratio of rats. As handling of the animals resulted in CBT elevations greater than observed at the highest exposure levels, future animal studies need to incorporate appropriate habituation periods before starting exposures.

3 Comments by the BfS

The goal and the methods of the presented research are valuable and relevant for radiation protection research. The present papers by Bala et al. and Sylvester et al. convincingly demonstrate the feasibility of unperturbed CBT measurements in unrestrained laboratory rodents during RF-EMF exposures. They show that exposure-induced average CBT increases are limited to about 0.4°C at a wbSAR of 5 W/kg in mice and to about 0.6°C at 4 W/kg in rats. By providing sufficient acclimatisation time to account for the stress-induced variations in CBT due to handling and invasive measurements [7] and by applying appropriate statistical testing, they were able to detect even small RF-EMF exposure-induced increases in CBT of about 0.15°C. This is in contrast to studies in rats by Kim et al. [8] and Ohtani et al. [9], who used a similar wireless thermometry device, but reported either no changes in CBT or increases of more than 1°C at wbSAR levels of 4 W/kg. However, these studies did not include a pre-exposure habituation period, did not sufficiently report exposure conditions such as ambient temperature [8], or performed exposures just a few days after surgery while the animals were still recovering [9].

The National Toxicology Program (NTP) conducted studies on the toxicological and carcinogenic effects of RF-EMF exposures in rats and mice. In a pilot study by Wyde et al. [10], body temperatures were measured in animals that were intermittently exposed (ten minutes on, ten minutes off) at different wbSAR levels. Aged male rats, whose body weight was comparable to a heavier subset of rats used by Bala et al., showed a statistically significant increase in temperature of about 0.65°C at a wbSAR of 6 W/kg, but no increase at a wbSAR level of 4 W/kg [10, 11], where Bala et al. found an increase of about 0.5°C after half an hour of exposure. There are several possible reasons why the results in rats for the wbSAR of 4 W/kg differ between the two studies. Firstly, due to the intermittent nature of the exposure in the NTP study, the average wbSAR was only 2 W/kg. Secondly, Wyde et al. used subcutaneously implanted microchips to record temperature. However, such measurements do not reflect the true CBT. Furthermore, temperature measurements were taken one to two minutes after the cessation of the last exposure of the intermittent exposure regime. This time delay would theoretically allow the CBT to drop by 0.016 to 0.032°C according to the data of Bala et al.

However, due to the differences in exposure conditions, it remains unclear whether and by how much Wyde et al. underestimated the true exposure-induced CBT changes in aged male rats in the NTP study [11].

Bala et al. and Sylvester et al. provide valuable methodologically validated insights for designing future studies requiring measurements of CBT in laboratory animals. Further detailed data on CBT responses as a function of varying body weights would contribute additional value.

In summary, the present papers provide a crucial methodological advance for RF-EMF research in the context of radiation protection. By establishing standardised, accurate, and minimally invasive methods for measuring core body temperature, they set the groundwork for reliably determining and quantifying thermal impacts of RF-EMF exposures in animal studies – an essential requirement for the interpretation of low-level RF-EMF bioeffects claims. Furthermore, the presented results regarding the changes in CBT of exposed mice and rats enable a better interpretation of previously published studies, which may not have employed such a rigorous approach with precise temperature control.

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