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OPINION

Electromagnetic pollution: another risk factor for infertility, or a red herring?

Alexander Lerchl

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Humans are exposed to radiofrequency electromagnetic fields (RF-EMF) from various sources (e.g., mobile and cordless phones, base stations, TV and radio transmitters, wifi adapters). So far, there is no evidence that would indicate that RF-EMF exposure is causing adverse health effects with respect to cancer, sleep disorder, headache, etc. Some results of *in vitro* and *in vivo* experiments revealed negative effects on male fertility. When looking at those studies in detail, many problems are identified with respect to correct dosimetry and proper experimental design. This field of research is notoriously difficult for various reasons, and experiments should be planned and performed with experts from the respective areas.

The increasing use of devices for wireless communication has given rise to fears that the radiofrequency electromagnetic fields (RF-EMFs) emitted by such devices (e.g., mobile and wireless phones, wifi adapters) and by their respective base stations cause various adverse health effects.[1,2] The list of such alleged effects is virtually endless, including sleep disturbances, headaches, tinnitus, high blood pressure, endocrine disorders, DNA damage, Alzheimer's disease and cancer. The vast majority of the many studies in cells, animals and humans, however, have provided no evidence whatsoever for such connections, even when the maximum allowed exposure levels were exceeded considerably. The discussion about possible health effects by exposure to RF-EMF recently has shifted towards infertility, mainly focusing on males.[3] The alleged decline in sperm counts—which is addressed in other contributions in this issue—is believed by some to be caused by RF-EMF emitting devices. Research in this area of research is notoriously difficult and prone to errors. In this paper, some common misunderstandings are addressed; limitations and technical problems are described as well.

Jacobs University Bremen, School of Engineering and Science, Bremen D-28759, Germany
Correspondence: Professor A Lerchl (a.lerchl@jacobs-university.de)
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ELECTROMAGNETIC FIELDS

Information exchange by wireless devices works by sending and receiving RF-EMF. Depending on the country, the device and the network, the frequencies used for mobile phones and wifi adapters are in the range of approximately 800–2800 MHz (0.8–2.8 GHz), and the corresponding wavelengths are in the range of approximately 10–40 cm. The maximum output power is 1 or 2 W for mobile phones and strongly depends on the distance to the nearest base station. In fact, modern mobile phones may reduce the output power by a factor of 1000 or more if the base station is nearby. This automatic reduction is not done to deliberately reduce exposure of the user, but has only a technical cause, namely, the reduction of energy consumption by the phones' batteries. For the same reason, mobile phones do not emit radiation while in the standby mode. Only from time to time (depending on the network, every 30 min to 8 h), do they send a short signal to the base station (periodic location update).

EXPOSURE LIMITS

On the basis of thermal effects (see below) which have to be prevented, maximum exposure levels were defined as basic restrictions in 1998 by the International Commission on Non-ionizing Radiation Protection[4] and have been adopted by most countries as by-laws. These limits are different for whole-body exposure and local exposure, and different for the general public and those with occupational exposure. The measure for exposure is the specific absorption rate (SAR) and the unit is watts per kilogram (W kg^{-1}).

The fact that the restrictions for occupational exposure are five times higher than those for the general public does not mean that exposed workers are at a higher risk, but reflects the introduction of an arbitrary precautionary reduction factor of 5 for the general public.

The SAR values are not directly measurable and depend on the frequency. Therefore, so-called reference levels have been defined that are comparatively easy to measure as electric field strengths with the unit volts per meter (V m^{-1}). For the frequency range 0.8–2.8 GHz, the reference levels are approximately 33–62 V m^{-1} (general public) and 49–92 V m^{-1} (occupational).

BIOLOGICAL EFFECTS: MYTHS AND REALITY

Thermal versus non-thermal effects

The only scientifically-assured biological effect of exposure to RF-EMF in the frequency range of mobile communication is heating (thermal effects). Below the exposure limits, however, potentially damaging temperature increases are prevented: while for whole-body exposure, thermal effects are negligible, local exposure (i.e., by using a mobile phone) leads to temperature increases of less than 1°C only in close proximity of the antenna, mainly in the ear pinna, the ear canal,[5] the skin and parts of the brain where the temperature increase due to exposure is on the order of 0.1°C.[6] One of the common misunderstandings by laymen is the warmth perception at the ear pinna after a long telephone call which is believed to be caused by RF-EMF. Studies have clearly shown that RF-EMF is responsible for only a small fraction of

this temperature increase, while the major contribution comes from the insulation (i.e., less heat dissipation by the ear pinna) and heating by the phone's battery and electric circuits during operation.[6]

'Radiation'

The electromagnetic fields emitted by mobile phones and other wireless devices are often called 'radiation' which is at least misleading. Radiation is the commonly used term for ionizing radiation, i.e., high-energy photons (e.g., UV-C, X-rays, γ-rays) or particles (α and β), which can ionize atoms and molecules and can therefore lead to mutations and cancer. The energy of the photons in the frequency range discussed here is approximately six orders of magnitude lower than the energy required for ionization (approximately 1 MeV). Therefore, from a physical point of view, direct mutagenic effects from exposure to RF-EMF are impossible.

That the term 'radiation' (instead of RF-EMF) is used by activists and producers of 'radiation protection chips' for mobile phones is understandable as a marketing device (or ploy), since their customers associate radiation with danger, while the term 'electromagnetic fields' is more neutrally perceived.

Exposure scenarios

It is also interesting to note that the fears of the public concerning RF-EMF sources concentrate mainly on the base stations, while the most relevant source, the mobile phones, are often ignored. In fact, owing to the close proximity of mobile phones to the user, the relative exposure from mobile phones is orders of magnitudes higher than that from base stations. In this regard, the irrational arguments often used to reduce exposure, by placing base stations outside communities, has had exactly the opposite effect, because the mobile phones have to emit at higher power output to establish communication with the base station.

International perspectives on health effects

In 2011, the International Agency for Research on Cancer (IARC), a subdivision of WHO, classified RF-EMF as 'possibly carcinogenic' (group 2B),[7] and this caused considerable public discussion. This classification is mainly based on one large international study, the so-called INTERPHONE project, which investigated the possible association of brain cancer incidence (glioma and meningioma) with the use of mobile phones.[8] While the overall results showed a significantly lower risk for users versus non-users, a more detailed *post hoc* analysis with 10 subgroups showed that only the group of heavy users with glioma had a significantly elevated risk; however, this methodology introduces the problem of multiple *post hoc* comparisons. The authors themselves acknowledged problems with the acquisition of the data (e.g., interviews of relatives as proxies when the patients had died; implausible data of duration of phone calls, selection bias, etc.).[9,10] Whereas some use the IARC classification as proof of their prophecy that RF-EMFs are dangerous, others—correctly—argue that this classification is unjustified. Drinking coffee and eating certain pickled vegetables have also been classified as 'possibly carcinogenic', without any known consequences. It appears that IARC simply wanted to avoid a clear decision, namely, a classification into the next higher (2A: probably carcinogenic) or next lower (3: not classifiable) category. The IARC monograph on this topic is expected to be published in 2013, when readers should be able to obtain some more insight into this classification. At any rate, IARC excluded base stations as relevant sources in terms of carcinogenicity, so that at least in this respect the situation has become somewhat clearer.

By analyzing the relevant literature, other international agencies and expert groups have assessed other possible adverse health effects of RF-EMF fields, i.e., not only focusing on cancer, and have come to different conclusions. In 2009, the International Commission on Non-ionizing Radiation Protection reconfirmed their earlier recommendations for exposure limits.[11] Another recent publication by the British Health Protection Agency clearly states that there is no reason to assume that health effects are to be expected by exposure to RF-EMF below the exposure limits.[12] The vast majority of scientists worldwide are convinced that the probability for adverse health effects as a consequence of increasing exposure to RF-EMF is close to zero.[13]

IMPACTS ON MALE FERTILITY

Many have investigated the effects of exposure to RF-EMF on the production and function of spermatozoa, both *in vivo* and *in vitro*.[14] Most studies were negative. A recent multigeneration study in mice, at different SAR levels of up to 1.3 W kg^{-1} (whole body), showed no negative effects whatsoever on male and female reproductive parameters, including numbers of offspring, malformations, sperm counts, malformed sperm and weights of reproductive organs.[15] While the results of this study, despite the fact that it was the largest of this kind so far, are not directly transferable to humans, they at least do not indicate an immediate and severe problem.

The general and notoriously difficult problem with *in vitro* studies is the fact that the RF-EMF energy absorbed by the samples will inevitably cause a temperature increase, depending on the field strength and the duration of exposure. In order to disentangle thermal from non-thermal effects, the exposed samples' temperatures have to be measured during (or at least after) exposure and cooling must ensure negligible temperature differences between exposed and sham-exposed samples whenever possible. Although it sounds like a problem easy to solve in theory, in practice, it is very difficult. To set the temperatures of the incubators at defined levels is certainly not sufficient. The other, likewise difficult, problem is the estimation of exposure as SAR levels, which requires detailed knowledge and sophisticated computer programs in order to model the SAR distribution and the associated temperature increases in the samples.[16] This is not only necessary for checking SAR differences between several samples in one exposure unit (e.g., a waveguide), but also for SAR distributions within one sample (i.e., differences between the center and the periphery of a sample in a Petri dish). These differences easily can be in the order of one magnitude so that thermal effects can occur, while the overall SAR values of the sample would indicate no thermal effects. In order to explain in detail the problems mentioned above, one study and the associated problems are described as an example.

de Iuliis *et al.*

In the study published by de Iuliis *et al.*[17] in 2009, isolated and purified human sperm samples were exposed to RF-EMF at various SAR values up to 27.5 W kg^{-1}, well above the

Table 1 Basic restrictions for exposure to RF-EMF (frequency range 10 MHz–10 GHz)[4]

Exposure characteristic	*Whole body average SAR (W kg^{-1})*	*Localized SAR (head and trunk) (W kg^{-1})*	*Localized SAR (limbs) (W kg^{-1})*
Occupational	0.4	10	20
General public	0.08	2	4

allowed exposure limits and clearly in the thermal range. However, some effects (lowered viability and motility, increased levels of reactive oxygen species and DNA fragmentation) occurred at levels of 1 W kg^{-1}, below the limits for localized exposure (**Table 1**). Thanks to the detailed, albeit difficult-to-extract information given in the paper, it is clear that the exposure conditions and the SAR estimations were far from state-of-the-art. The exposed and the sham-exposed samples were handled differently by putting them inside or outside the exposure unit, respectively. It is standard procedure today to have identical exposure units and sham-exposure units, in order to ensure identical conditions (except for RF-EMF exposure) and a blind design. The most significant problem was the way the SAR values were calculated. Instead of doing state-of-the-art dosimetry with established methods,[16] the temperature increase of a saline sample before and after exposure was measured and an SAR value was somehow obtained and served as reference for the others. The temperature rises were measured after exposure for a maximum of 120 s, while the exposure of the samples lasted for 16 h. Finally, the samples for temperature increase measurements were made in saline, while the real samples with spermatozoa were suspended in a buffer with polyvinyl alcohol, which is very different in conductivity and permittivity, leading to considerable differences in SAR values at identical field strengths. Therefore, the SAR values in the sperm samples were very likely considerably higher than in the saline sample. Taken together, the lack of appropriate dosimetry and temperature control during exposure makes it very difficult to accept the reported effects as not being caused by thermal effects, even at the lower SAR levels.

The three retracted papers by Salama *et al.*

Three studies by Nader Salama on catastrophic effects of RF-EMF of male rabbits' reproductive functions were published in three renowned journals in 2009 and 2010.[18–20] According to the authors, who allegedly performed their studies in a Japanese laboratory, the animals were kept squeezed in small cages for 8 h per day for 12 weeks during their 'exposure' from a mobile phone glued to the outside of the cage, under the rabbits' scrota. The mobile phones were set to the stand-by mode and thus did not produce any RF-EMF—there was no exposure! Still, the 'exposed' animals reacted with dramatic and sudden drops in sperm counts, sperm motility, seminal fructose levels, etc. and those levels were very stable after the drop, i.e., they looked like a mathematical function rather than a curve of a biological effect—too good to be true.[21]

The author of this paper thought that these effects looked really strange and had a look at the other two papers by Salama on rabbits. It turned out that they also contained such strange figures. Moreover, two Figures and parts of Tables were identical in the papers, despite the fact that they were, according to the authors, collected in different experiments. A concerted investigation by the journals revealed that the Japanese authors had not been informed about the publication and that no lab books could be found in the laboratory. Consequently, all three papers were retracted in 2012.

CONCLUSIONS

The possible impact of cell phone 'radiation' on male fertility is a hot topic, mainly because some scientists, politicians and certainly large parts of the public are fascinated by horror scenarios such as this one. As long as poorly-controlled studies on the effects of RF-EMF exposure on sperm function and fertility continue to be conducted and published, this will not change. The correct dosimetric assessment of exposure, i.e., the estimation of the real SAR values, is a notoriously difficult area of research, both *in vivo* and *in vitro*, and it requires detailed knowledge in biophysics, physics and electromagnetic theory. Only when scientists from all relevant disciplines work together, can reliable exposure conditions be achieved and proper risk analyses be performed. So far, there are no indications for adverse effects of RF-EMF on male and female fertility parameters, either *in vivo* or *in vitro*.[12]

COMPETING FINANCIAL INTERESTS

The author declares that he has no competing financial interests in relation to this paper.

1 Repacholi MH, Lerchl A, Roosli M, Sienkiewicz Z, Auvinen A *et al*. Systematic review of wireless phone use and brain cancer and other head tumors. *Bioelectromagnetics* 2012; **33**: 187–206.
2 Feychting M. Mobile phones, radiofrequency fields, and health effects in children—epidemiological studies. *Prog Biophys Mol Biol* 2011; **107**: 343–8.
3 La Vignera S, Condorelli RA, Vicari E, D'Agata R, Calogero AE. Effects of the exposure to mobile phones on male reproduction: a review of the literature. *J Androl* 2012; **33**: 350–6.
4 International Commission on Non-Ionizing Radiation Protection. Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). *Heatlh Phys* 1998; **74**: 494–522.
5 Tahvanainen K, Nino J, Halonen P, Kuusela T, Alanko T *et al*. Effects of cellular phone use on ear canal temperature measured by NTC thermistors. *Clin Physiol Funct Imaging* 2007; **27**: 162–72.
6 van Leeuwen GM, Lagendijk JJ, van Leersum BJ, Zwamborn AP, Hornsleth SN *et al*. Calculation of change in brain temperatures due to exposure to a mobile phone. *Phys Med Biol* 1999; **44**: 2367–79.
7 Baan R, Grosse Y, Lauby-Secretan B, El Ghissassi F, Bouvard V *et al*. Carcinogenicity of radiofrequency electromagnetic fields. *Lancet Oncol* 2011; **12**: 624–6.
8 INTERPHONE Study Group. Brain tumour risk in relation to mobile telephone use: results of the INTERPHONE international case–control study. *Int J Epidemiol* 2010; **39**: 675–94.
9 Saracci R, Samet J. Commentary: call me on my mobile phone…or better not?—a look at the INTERPHONE study results. *Int J Epidemiol* 2010; **39**: 695–8.
10 Swerdlow AJ, Feychting M, Green AC, Leeka Kheifets LK, Savitz DA *et al*. Mobile phones, brain tumors, and the interphone study: where are we now? *Environ Health Perspect* 2011; **119**: 1534–8.
11 International Commission for Non-Ionizing Radiation Protection. ICNIRP statement on the ''guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)''. *Health Phys* 2009; **97**: 257–8.
12 Health Protection Agency. Health effects from radiofrequency electromagnetic fields. 2012. http://www.hpa.org.uk/webc/HPAwebFile/HPAweb_C/1317133827077
13 Zur Nieden A, Dietz C, Eikmann T, Kiefer J, Herr CE. Physicians appeals on the dangers of mobile communication—what is the evidence? Assessment of public health data. *Int J Hyg Environ Health* 2009; **212**: 576–87.
14 Merhi ZO. Challenging cell phone impact on reproduction: a review. *J Assist Reprod Genet* 2012; **29**: 293–7.
15 Sommer AM, Grote K, Reinhardt T, Streckert J, Hansen V *et al*. Effects of radiofrequency electromagnetic fields (UMTS) on reproduction and development of mice: a multi-generation study. *Radiat Res* 2009; **171**: 89–95.
16 Iyama T, Ebara H, Tarusawa Y, Uebayashi S, Sekijima M *et al*. Large scale in vitro experiment system for 2 GHz exposure. *Bioelectromagnetics* 2004; **25**: 599–606.
17 De Iuliis GN, Newey RJ, King BV, Aitken RJ. Mobile phone radiation induces reactive oxygen species production and DNA damage in human spermatozoa *in vitro*. *PLoS ONE* 2009; **4**: e6446.
18 Salama N, Kishimoto T, Kanayama HO, Kagawa S. Effects of exposure to a mobile phone on sexual behavior in adult male rabbit: an observational study. *Int J Impot Res* 2010; **22**: 127–33. Retracted.
19 Salama N, Kishimoto T, Kanayama HO, Kagawa S. The mobile phone decreases fructose but not citrate in rabbit semen: a longitudinal study. *Syst Biol Reprod Med* 2009; **55**: 181–7. Retracted.
20 Salama N, Kishimoto T, Kanayama HO. Effects of exposure to a mobile phone on testicular function and structure in adult rabbit. *Int J Androl* 2010; **33**: 88–94. Retracted.
21 Lerchl A, Bornkessel C. Letter to the Editor on 'Effects of exposure to a mobile phone on testicular function and structure in adult rabbit' by Salama *et al*. *Int J Androl* 2010; **33**: 95; author reply 6–7.