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Review

Shielding methods and products against man-made Electromagnetic Fields: Protection versus risk

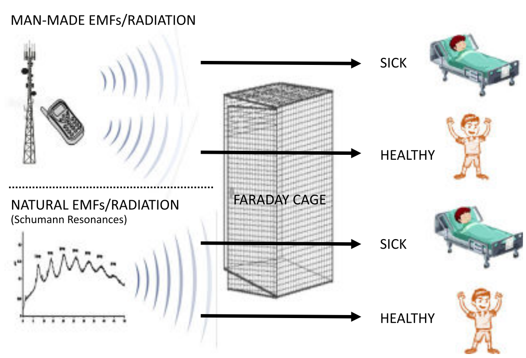
Dimitris J. Panagopoulos [a,b,c,*], George P. Chrousos [b]

[a] National Center for Scientific Research "Demokritos", Athens, Greece
[b] Choremeion Research Laboratory, Medical School, National and Kapodistrian University of Athens, Greece
[c] Radiation and Environmental Biophysics Research Laboratory, Athens, Greece

HIGHLIGHTS

- Human exposure to man-made EMFs has increased with increasing health problems.
- Metal shielding is lately suggested by private companies/individuals as a way to reduce exposure.
- Metal shielding reduces both man-made and natural atmospheric EMFs.
- EHS symptom relapses and internal desynchronization are reported after shielding.
- An avoidance strategy of man-made EMFs should be preferable than metal shielding.

GRAPHICAL ABSTRACT



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ABSTRACT

Human exposure to man-made Electromagnetic Fields (EMFs) has increased to unprecedented levels, accompanied by increase in various health problems. A connection has been indicated by an increasing number of studies. Symptoms characterized as Electro-hyper-sensitivity (EHS) are frequently reported especially in urban environments. Lately, people are advised by private companies and individuals to protect themselves from man-made EMFs by metal shielding through various products, for which there are reasonable concerns about their protective efficacy and safety. Indeed, any metal shielding practice, even when correctly applied, attenuates not only man-made totally polarized EMFs accused for the health problems, but also the natural non-polarized EMFs responsible for the biological rhythmicity and well-being of all animals. Strong evidence on this was provided by pioneering experiments in the 1960's and 1970's, with volunteers staying in a shielded underground apartment. We analyze the physical principles of EMF-shielding, the importance of natural atmospheric EMFs, and examine available shielding methods and suggested products, relying on science-based evidence. We suggest that an avoidance strategy is safer than shielding, and provide specific protection tips. We do not reject shielding in general, but describe ways to keep it at a minimum by intermittent use, as this is theoretically safer than extensive permanent shielding. We explain why metallic patches or "chips" or minerals claimed by sellers to be protective, do not seem to make sense and might even be risky. We finally suggest urgent research on the safety and efficacy of shielding methods combined with use of generators emitting weak pulses of similar frequency, intensity, and waveform with the natural atmospheric resonances.

* Corresponding author at: Laboratory of Health Physics, Radiobiology & Cytogenetics, Institute of Nuclear & Radiological Sciences & Technology, Energy & Safety, National Center for Scientific Research "Demokritos". 60037, Ag. Paraskevi, Athens, Greece.
E-mail address: dpanagop@biol.uoa.gr (D.J. Panagopoulos).

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Contents

1. Introduction: Health effects of man-made EMFs and “protective” products

Human exposure to man-made Electromagnetic Fields (EMFs) has increased tremendously in recent years. In parallel, there is an ever increasing number of people reporting a variety of health problems, while many private companies advertise and sell a variety of “health” services and products of non-evidence based value.

Exposure of people to the totally polarized EMFs of the human technology, especially Radio Frequency (RF) or microwave (in the GHz range) and Extremely Low Frequency (ELF) (0–3000 Hz) EMFs from Mobile Telephony (MT) antennas, and ELF 50–60 Hz electric and magnetic fields from power lines, has increased to unprecedented levels in order to satisfy the increasing demands of technological applications used by the modern society (Sangeetha et al., 2014; Panagopoulos et al., 2015; Buckus et al., 2017). Both ELF and RF/microwave EMFs have been classified as possible human carcinogens (“2B Group”) by the International Agency for Research on Cancer (IARC, 2002, 2013).

A large number of studies published in peer-review international scientific journals have found a variety of biological effects, (including the most detrimental ones such as DNA damage, cell death, and infertility) to be induced by exposure to either RF or ELF man-made EMFs (Agarwal et al., 2008, 2009; Balmori, 2005, 2006, 2010; De Iuliis et al., 2009; Panagopoulos, 2011, 2017, 2019). Moreover, epidemiological studies report an increasing connection between ELF or RF EMF exposure and cancer (Draper et al., 2005; Kheifets et al., 2010; Hardell et al., 2007, 2009, 2013a, 2013b; Khurana et al., 2009; Wang and Guo, 2016; Momoli et al., 2017).

A pathological syndrome on humans, initially reported by the German medical doctor Erwin Schliephake in 1932, then by Soviet researchers in the 1950's, and reappeared massively and rapidly increasing during the past 10–20 years, is called electro-hypersensitivity (EHS) or “microwave syndrome” and includes headaches, anxiety, sleep disorders, fatigue, etc. (Schliephake, 1932; Johnson-Liakouris, 1998; Santini et al., 2002; Navarro et al., 2003; Hutter et al., 2006; Abdel-Rassoul et al., 2007; Blettner et al., 2009; Kundi and Hutter, 2009; Gómez-Perretta et al., 2013; Shahbazi-Gahrouei et al., 2014; Belpomme et al., 2018). Similar effects that were previously categorized as medically unexplained symptoms (MUS) are recently attributed to chronic stress and inflammation (Tsigos et al., 2015). Continuing efforts are being made to find and establish objective methods for EHS evaluation, which is most important for its diagnosis and effective treatment (Rea et al., 1991; McCarty et al., 2011; Havas, 2013; Heuser and Heuser, 2017; Irigaray et al., 2018a, 2018b).

In recent years many private companies and individuals suggest to people concerned about the effects of man-made EMFs on their health - and especially to those suffering from EHS - to use metal shielding against MT and related types of RF/microwave EMFs usually emitted by antenna towers in the neighbourhoods. These include metal grids or paints for shielding buildings/spaces, and a variety of products to protect from their own mobile phones and other EMF-emitting devices. People are asked to pay considerable amounts of money in order to shield their homes, buy shielding clothes, shielding bed canopies, and a variety of other products to protect them from their own devices.

If that practice worked, it would indeed be a solution to provide protection for the human health in working/residential environments of increased EMF exposure levels. Unfortunately, the topic is complicated, and in fact it can be a risky practice as we shall explain below. This is probably the reason why there is an almost complete lack of experimental peer-reviewed studies verifying the efficacy and safety of such shielding products and practices.

2. Shielding properties of metals

2.1. Principles of EMF-shielding

Shielding the buildings against EMFs is accomplished by metal grids or paints covering the walls and ceilings, and films (containing metal grids) or curtains for the windows. A variety of sophisticated shielding materials has been developed including rubber with iron powder mixture (Lapkovskis et al., 2017). Moreover, a variety of products such as shielding garments, sleep shielding (bed canopies, sheets, blankets containing metal grids), etc., have appeared on the market.

The shielding properties of all these materials and products are based on the conductivity of the metal elements they contain. All conductive materials/objects concentrate on them and reflect electromagnetic waves/EMFs due to the existence of free carriers (charged particles able to move freely) within their masses. The higher the conductivity is, the more increased the EMF/wave-attraction and reflectivity. The most conductive materials are metals. All metallic surfaces/grids insulate electromagnetically by reflecting backwards upcoming electromagnetic waves due to their free electrons. These are the outer or valence electrons in all metal atoms, weakly bound to their nuclei. They can be easily detached from their atoms and flow in the form of a cloud within the entire metallic mass. Free electron clouds displaced towards positive electrical potentials and repelled by negative ones, attract and immediately reflect external EMFs/Electromagnetic Radiation (EMR) directed towards the metallic surface or grid rendering the space surrounded by the grid electrically neutral (in zero electrical potential). This effect, called electromagnetic coupling, was originally studied by Faraday and other pioneers and such grids are often called Faraday cages (Alexopoulos, 1973; Tsaliovich, 1995).

It is the displacement of the free electron cloud against the direction of the external electric field that concentrates the force lines of the field on any metallic/conductive object and diminishes the electric field and consequently the energy of upcoming electromagnetic waves in the space behind the object. If in addition, the metallic object/surface/grid is made from ferromagnetic metal (Fe, Co, Ni), it diminishes the magnetic field as well in the space behind it by concentrating the magnetic force lines on it, and in such a case the shielding is more effective (Alonso and Finn, 1967; Alexopoulos, 1973; Jackson, 1975; Tsaliovich, 1995). Radar operation is based on this effect for detecting metallic objects (ships, aircrafts, etc.). Electromagnetic waves emitted by the radar are reflected by metallic objects and return to the radar forming a spot on its display. Non-conductive objects such as wooden ships are not detected by radars.

Thus, all metal grids/surfaces, and especially ferromagnetic ones, will insulate their surrounded space from all external EMFs at all frequencies. They are not frequency-selective except that the lower the EMF frequency is, the more penetrating the EMF/EMR.

The "penetration depth" δ for plane electromagnetic waves within a material (defined as the depth at which the wave is damped to $1/e = 0.368$ of its initial amplitude), is given by the equation:

$$\delta = \sqrt{\frac{2}{\mu\omega\sigma}} \tag{1}$$

(where $\omega = 2\pi f$, f the frequency of the wave, and μ, σ the magnetic permeability and specific conductivity of the material respectively) (Ludwig, 1974; Jackson, 1975). As denoted by the equation, the higher the frequency and the conductivity are, the smaller the penetration. Thus, metals having higher conductivities than all other materials prevent EMF penetration more effectively. Moreover, ferromagnetic metals (with $\mu \gg 1$) prevent penetration and shield from upcoming EMFs/EMR even more effectively than other metals. A practical conclusion is that any metallic shield will attenuate all EMFs coming from outside, and increase all EMFs coming from inside the shielded space. Grounding the metallic shield will - theoretically - only increase its reflecting capacity.

EMFs emitted from inside the space, such as 50–60 Hz power EMFs, microwave emissions from mobile phones, cordless domestic phones (DECT), wireless internet routers (Wi-Fi), microwave ovens, etc., will be reflected backwards multiple times and trapped by the metallic shield inside the shielded space, i.e. the interior of the house. As a result, their levels will increase.

Moreover, and most importantly, external natural ELF EMFs such as the terrestrial electric and magnetic fields or the atmospheric EMFs (Schumann resonances) responsible for the excitation and rhythmicity of all animals/humans brain electrical activity, absolutely vital/necessary for any animal's physiological function and well-being, will be attenuated as well with potential long-term adverse consequences, as we analyze below (Schumann, 1952; Presman, 1977; Dubrov, 1978; Wever, 1970, 1973, 1979).

Although as explained, RF/microwave EMFs will be reflected more effectively by any metallic shield than the ELF EMFs, significant experimental evidence suggests that the most bioactive constituents of MT and related types of modern telecommunication EMFs are the ELF pulsing and modulation, not the RF carrier wave itself. In many experiments since the mid 1970's on many different biological endpoints, it is repeatedly shown that unmodulated continuous wave RF EMFs of different frequencies had little or no effect, while the same RF signals modulated by pulsed or sinusoidal ELF fields were bioactive (Bawin et al., 1975, 1978; Frei et al., 1988; Bolshakov and Alekseev, 1992; Penafiel et al., 1997; Huber et al., 2002; Höytö et al., 2008; Franzellitti et al., 2010; Campisi et al., 2010). In addition, ELF EMFs alone (without any RF carrier) are found to be independently bioactive as are RF EMFs modulated or pulsed by ELFs (Bawin and Adey, 1976; Goodman et al., 1995; Panagopoulos et al., 2013). All these experimental results are in agreement with the Ion Forced-Oscillation mechanism for the action of EMFs on cells which predicts that the bioactivity of a polarized EMF is inversely proportional to its frequency, practically meaning that in the case of EMFs that include a combination of RFs and ELFs, the ELF components (pulsing and modulation) are actually the bioactive ones (Panagopoulos et al., 2000, 2002, 2015). A grid thick and dense enough to attenuate effectively man-made ELFs will inevitably attenuate the natural ELFs as well.

2.2. EMF-shielding measurements

In order to have an estimation how much EMFs can be attenuated by metal shielding, we measured the electric and magnetic component of the 50 Hz EMF emitted by a simple lamp switch with a ME 3030B ELF field meter (Gigahertz Solutions, Germany), at 5 cm distance from the switch. We used a piece of grid made from galvanized iron (available on the market) and gave it a single-layer cylindrical shape that the field meter could be inserted within the cylinder without being in touch with the grid. The wire thickness was 1 mm, and the mesh openings 1 cm × 2.5 cm. The electric (E) and magnetic (B) field readings excluding the background were: a) Without shielding: E = 30 V/m, B = 0.15 mG. b) With shielding: E = 9 V/m (70% decrease), B = 0.13 mG (13.33% decrease). Since Schumann resonances and their harmonics are in the same frequency range (~8–100 Hz), the above attenuation provides a representative estimation of how much they are attenuated as well by such a metal grid.

The same metal grid reduced the RF EMF (~1950 MHz) from an active UMTS (Universal Mobile Telecommunications System) mobile phone in "talk mode" at 5 cm distance, from ~15 $\mu W/cm^2$ to ~3 $\mu W/cm^2$ (~80% decrease) as measured by a Cornet ED-85EX Plus (Cornet Microsystem Inc., USA) RF field meter. The field meter and the grid were well outside the mobile phone's near-field which extends ~2.45 cm from the device.

These are indicative measurements to provide an approximation of how much ELF and RF EMFs are reduced by metal shielding. As we can see, indeed the metal grid reduced the RF signal more than the ELF fields, but not much more, especially compared with the reduction in the electric component of the ELF field. If we used a thicker and/or denser metal grid as in Panagopoulos and Margaritis (2010) the attenuation in both RF and ELF bands could be significantly greater.

3. Natural atmospheric EMFs and their importance for life

The global lightning activity, i.e., electromagnetic waves produced by the atmospheric discharges during thunderstorms, creates an electromagnetic background oscillating in the lower ELF band within the earth-ionosphere shell cavity. The first observations of global electromagnetic resonances were made by Nicola Tesla (1905). Winfried O. Schumann (1952) studied theoretically this phenomenon and predicted the frequencies of these resonances which became known as "Schumann resonances". Later they were measured to have maxima at 7.8, 14.2, 20.3, 25.9, 32.0, ~39, and ~45 Hz (Balser and Wagner, 1960; Koenig, 1974; Nieckarz et al., 2009; Persinger, 2014). These atmospheric electromagnetic oscillations can be measured with specialized instrumentation in the lower ELF band at locations away from man-made ELF EMF-sources such as 50–60 Hz power lines, etc. (Barr et al., 2000; Price et al., 2007; Votis et al., 2018).

It is amazing, and - of course - of utmost importance that the basic frequency of the global electromagnetic resonances (7.8 Hz) coincides with the basic frequency of the alpha rhythms of the human brain electrical oscillations (7.8–13 Hz) as was already recorded in electroencephalograms (EEG) by Hans Berger since the mid 1920's (Berger, 1929; Schienle et al., 2001; Persinger, 2014).

Knowing the connection between Berger's and Schumann's discoveries, Ruetger A. Wever a biophysicist at the Max Planck institute in Germany, conducted series of pioneering experiments for more than a dozen of years continuously during 1960's and 1970's. The participants (a total of 232 volunteers) stayed for several weeks (29 days on average) within two identical underground apartments, the one of which was equipped with metal shielding in the walls (unknown to the subjects). The metal shielding was prohibiting the natural atmospheric (Schumann) EMFs (and the static terrestrial electric and magnetic fields as well) to penetrate in the shielded apartment.

The experiments showed that the circadian rhythms of the individuals (activity, temperature sleep/waking cycles, secretions, etc.) in the shielded apartment began to desynchronize from their normal 24 h-period, acquiring within a week a longer period of up to 28.5 h. This phenomenon, called "internal desynchronization", did not occur in the control subjects who participated in the experiments staying within the identical not shielded underground apartment. By turning on an electric pulse generator in the shielded apartment (also unknown to the subjects) producing 2.5 V/m square pulses with a frequency at 10 Hz, the rhythms of the individuals in the shielded apartment were synchronized again and differences in the rhythms among individuals were diminished. When the generator was turned off, immediately, internal desynchronization started again. In contrast to the 10 Hz electric field, static electric or magnetic fields could not restore synchronization The illumination in both apartments during the experiments was either self-controlled by the participants, either constant. Therefore in both cases there was no light-dark periodicity in both apartments. In addition, the participants in both apartments were free to leave the apartments any time without contacting the experimenter. Still, only in the shielded apartment the people became desynchronized. The obvious conclusions were that, a) the natural atmospheric (Schumann) EMFs constitute a pacemaker for the human/animal biological rhythms, b) the 10 Hz field compensated for their absence, and c) this atmospheric EMF-pacemaker seems to be determinant for internal synchronization independently from the night-day (light-dark) periodicity (Wever, 1970, 1973, 1974, 1979).

The shielding in these experiments was quite intense and consisted of five thin layers/sheets of iron (mild steel) plus additional structural steel in the walls, which resulted in strong attenuation of the terrestrial static magnetic field by 99%. Orientation by magnetic compass or radio reception, were not possible within the shielded apartment while they were unaffected in the non-shielded one (Wever, 1974, 1979).

The reason Wever and his co-workers chose a 10 Hz pulsing electric field to restore synchronization was that this frequency is close to the basic Schumann frequency which is now known to be 7.8 Hz. Originally Schumann had theoretically calculated this frequency to be 10.6 Hz, according to his formula,

$$f_n = \frac{c}{2\pi R}\sqrt{n(n+1)} \quad (2)$$

or $f_n = 7.5\sqrt{n(n+1)}$, for $n = 1$ ($n = 1,2,3, \ldots$). f_n (in Hz) the frequencies of the atmospheric electromagnetic resonances, c the velocity of light in the earth–ionosphere cavity (~3×10^8 m/s), $2\pi R$ the earth's circumference (~4×10^7 m), and R the average earth's radius (Schumann, 1952). A few years later, detailed measurements revealed that although Schumann's calculations were accurate, the measured frequencies are a little lower than those predicted by Schumann's formula because of ionospheric losses (Schumann, 1952; Balser and Wagner, 1960; Koenig, 1974; Barr et al., 2000; Price et al., 2007; Nieckarz et al., 2009; Votis et al., 2018). Although in Wever's experiments the 10 Hz field was very effective in restoring synchronization, we may now reasonably speculate that a 7.8 Hz field would be even more effective.

It is most important to emphasize that long-term internal desynchronization is linked to a variety of health problems including depression, sleep disorders, impulsivity, mania, metabolic syndrome, cardiovascular disease, and increased cancer risk (Reinberg et al., 2007; Salgado-Delgado et al., 2011; Shanmugam et al., 2013).

Therefore, it is evident that the human/animal circadian rhythmicity, as well as the physiological electrical activity of the brain, are excited and attuned by the natural atmospheric ELF EMFs. Cells and living organisms are subtle and accurate electric circuits with weak transient electric currents consisting of free ion flows through cells and tissues, practically controlling every cellular/biological function (Nucciteli, 1992; McCaig et al., 2005; Panagopoulos, 2013). This subtle endogenous electrical activity is controlled and attuned by the natural atmospheric EMFs (Wever, 1970, 1973, 1974, 1979; Presman, 1977; Dubrov, 1978; Kato, 2006; Persinger, 2014; Panagopoulos and Balmori, 2017). Thus, although electrical activity in the human/animal body is produced by depolarizations/repolarizations of cell membranes (Alberts et al., 1994), the rhythms of these phenomena in the brain - and consequently in the entire body - are synchronized by ultradian and circadian biological clocks with alpha brain waves corresponding to Schumann resonances.

Attenuating these natural EMFs will ultimately result in disrupting the physiological function of any living organism. The health problems reported by submarine personnel (completely shielded from the natural EMFs due to the closed metallic walls and the conductive sea water) can be explained on the same basis. These facts suggest that any personnel working in any spaces with metallic walls (submarines, ships, aircrafts, etc.), should spend as many hours as possible outside during the rest hours of their days. The metal grids or paints usually applied to shield houses may not insulate as intensely as do thick metallic walls or even the successive thin layers in Wever's experiments, but the attenuation of the natural EMFs that they will bring about may have long-term adverse consequences.

It seems that the reason why man-made EMFs/EMR are damaging to human/animal health, while natural EMFs/EMR at normal exposure levels are vital, is that man-made EMFs are totally polarized and coherent while natural ones are unpolarized or partially polarized and incoherent (Panagopoulos et al., 2015). Unfortunately any metal shielding not only is not frequency selective, but neither polarization selective. Thus, it will attenuate both man-made (polarized) and natural (upolarized) EMFs/EMR.

4. Analyzing current shielding methods and products

4.1. Shielding against outdoor EMF-sources

It has been reported that house shielding by metal grids or paints can play a beneficial role alleviating some of the symptoms experienced by EHS people. It is admitted though, that "there is much space for subjective considerations" (EHS Foundation, 2013). It has also been reported that on many occasions after an initial period of retreat, symptoms relapsed and were even worse than before (Carlo, 2008). Symptom relapses have been admitted even by companies that sell shielding materials: "If you are sensitive and you feel worse after shielding material is installed and the high frequency radiation is in fact lower than before the shielding…" (https://www.emf-detector.org/reduce-emf/successful-shielding/).

A great disadvantage of all existing up to today reports on EMF-shielding effects is that they are not published in peer review scientific journals or books, but in bulletins and internet pages. This is due to the lack of well-designed rigorous studies based on scientific methodology to find out whether indeed metal shielding can alleviate the symptoms experienced by EHS people. Certainly it is not easy to carry out such studies due to difficulties in objective tests evaluating EHS, and the fact that the relapse of symptoms may take months or years, after the shielding.

Theoretically, total permanent metal shielding of a house should only be done in the hypothetical case in which it is ensured that the natural atmospheric EMFs (Schumann resonances) are highly penetrating after the shielding. Apart from the fact that this is rather unlikely according to the measurements and analysis presented in section 2, it is almost impossible to directly verify this, especially in modern residential environments. It takes very specialized instrumentation (ELF spectrum analyzers with suitable filters to suppress the noise due to power lines and other ELF man-made sources) to take credible measurements at intensities down to 0.02–2 mV/m, or 0.5–1.5 pT. Apart from locations far away from man-made EMFs, the weak Schumann oscillations will be totally masked by the much stronger man-made ELF emissions (Koenig, 1974; Ludwig, 1974; Price et al., 2007; Votis et al., 2018). [Fortunately, "masked" does not mean they are cancelled. They are there but not easily detected due to limitations of our instrumentation.] In practice, and in terms of testing whether Schumann resonances remain unaffected after shielding, the materials used for shielding can be tested against any EMF source operating at power frequency 50–60 Hz. If both the electric (E) and magnetic (B) components of the 50–60 Hz field remain largely unaffected after shielding (which is unlikely), then probably Schumann resonances are unaffected as well. A more accurate testing would be measuring the E-B attenuation by the shielding material on the exact Schumann frequencies emitted by a specifically constructed generator.

Total permanent metal shielding of a house would permanently attenuate natural EMFs, and would also increase EMF levels from sources inside the house and thus, it should be avoided, even when combined with a generator emitting Schumann resonance frequencies, due to the current lack of long-term experimental data verifying its safety. Unfortunately, current architectural EMF-shielding methods do not consider at all the effects of shielding on the Schumann resonances (Hemming, 1992). Moreover, any sharp corners and edges of the shielding material can cause large field increases in their vicinity due to field distortion called "corner effect" (Ludwig, 1974).

Partial/selective permanent shielding of certain walls of a house (e.g. in the direction of the neighbourhood's antenna tower) is also risky, since polarized EMFs/EMR of the same polarization (as e.g. from all MT base antennas vertically oriented) can create constructive interference effects, i.e. spots of increased intensity, at unpredictable locations behind a shielded surface (Panagopoulos et al., 2015). Radiation will be diminished right behind a metal patch (e.g. a single wall) but it may increase at other locations due to interference. Moreover, in case that the network of antennas in the area changes by e.g. addition of more antennas, the entire situation may change dramatically.

Using metal patches to diminish radiation behind the patch, is generally risky because, as with any partial shielding, there may be hardly detectable spots of increased radiation due to interference at different other locations in the body. As explained, all metallic objects concentrate on them EMFs/EMR by electromagnetic coupling and immediately reflect them. This means, on the one side of the metal object/surface towards the EMF-source, intensity increases, while on the other side decreases. Thus, all metallic objects, including metallic minerals, such as shungite, claimed to protect from EMFs/EMR (Kurotchenko et al., 2003) should be avoided close to the body of an EHS person since they can increase exposure. Alleged protective effects from such products do not seem to make any sense.

In any case, the aspect of permanent house shielding (total or partial), in combination with elimination of indoor EMF-sources, and use of a pulse generator emitting weak pulses at the Schumann resonance frequencies, should be carefully and urgently investigated by long-term animal experiments, given the fact that man-made electromagnetic pollution is constantly increasing. Perhaps, the use of polarizing materials instead of metal grids, which would selectively cut only the vertically polarized EMFs emitted by antennas, should be carefully investigated as well.

The use of a shielding bed canopy during sleep would - theoretically - be safer than permanent shielding of the house on the condition that any electric/electronic device should be out of the canopy (and better turned off) during sleep. In such a case, it is possible that any trend for internal desynchronization due to the attenuation of the natural EMFs during the sleep time will be restored during the remaining hours of the day. This option of intermittent shielding also seems to be safer than wearing shielding garments for the following reasons: a) Clothe shielding is partial on certain parts of the body only. Head or fingers and possibly other parts of the body are usually not covered. b) The person wearing shielding clothes is moving. c) Any contact of the skin with the metal grid of the garment may increase exposure locally.

Another option of (partial) clothe shielding is wearing metal grid caps (called "sleeping caps") on the head during sleep or even during the daytime. A recent article reported that from 64 EHS patients who were asked to wear metal grid caps on their heads for 4 h during sleep and for another 4 h during normal activity, 90% reported a "definite or strong change in their symptoms" (Marshall and Rumann Heil, 2017). This article did not include statistical analysis, there was no control cap without metal grid to test for a possible placebo effect, and did not report whether the "change in the symptoms" was an improvement or worsening.

As explained already, one of the great dangers with partial shielding is that radiation can create interference spots of increased intensity at non-shielded parts of the body. This greatly depends on the position of the person in relation to the source(s). When a partially shielded person is moving, the spots of interference change unpredictably. In such a case the exposure on the non-shielded parts, as e.g. the head, may increase considerably at different instances/positions during movement. Moreover, as the metallic grid will attract upcoming EMFs on its external surface, wherever it touches the skin, it may increase the local exposure instead of decreasing it.

These effects can be prevented with the bed shielding, which is total and invariable during sleep. But even this, is not actually as simple as it looks. In order for the bed shielding to be effective and - theoretically - safe, again, the subjects must not be in touch with the metal grid either directly or via any conductive material, meaning that e.g. the bed must not be made from metal, otherwise, as explained above, the EMFs collected by the grid will pass to the subjects and increase exposure at contact locations instead of decreasing it. These are examples of why shielding practices can be risky. In order for this suggestion to be definitely a safe shielding solution, verification should also be undertaken by long-tern animal experiments.

Certainly, short-term shielding of control animals for a few days is an accepted methodology in bioelectromagnetic experiments (Balmori, 2010; Panagopoulos and Margaritis, 2010). This is different from living in a shielded space for years or for life. The occurrence of internal desynchronization will normally have no effect on health and well-being of the animals if it only lasts for a few days (Wever, 1979).

4.2. Shielding against EMF-emitting devices

Another recent phenomenon is a variety of products appeared on the market called "health chips", "EMF radiation protection chips", "mobile phone shields", etc., that supposedly reduce the adverse health effects of mobile phones by "reducing radiation levels" or "reducing the gradients of the magnetic fields" or "smoothing the peaks", or "alter the radiation into a form that does not produce adverse health effects", or "transform and neutralize the harmful effects of EMFs by radiating a protective field when placed directly on devices", etc. These are usually in the form of patches that the users should stick on their mobile phones and other electronic devices, supposedly protecting them from the radiation emitted by these devices. This does not seem to bear any scientific explanation.

One cannot modify the radiation (frequency, waveform) once it has been emitted by a device. One can only attenuate it (reduce its intensity). Modification would only be possible by modifying the electronic circuits within the devices. Even if that were the case with these products, which is not, once the emitted signal is modified or attenuated, the device (mobile phone, etc.) would lose its ability to connect with the network and communicate. If one simply attenuates the signal without modifying it, which is possible, the mobile phone again will have difficulty in establishing connection with the base antennas and automatically will emit a stronger signal/radiation/EMF in order to be able to connect/communicate (Panagopoulos, 2011). This is why it is dangerous to put the mobile phone within any kind of metal box/sheath/holster etc. in order to carry it on the clothes/body while it is turned on. Any such product will attenuate the incoming signal, and thus it will attenuate the connectivity of the mobile phone. The less the connectivity is, the stronger the emission of the device becomes in order to be able to connect with the network.

Therefore, it hardly makes any sense that sticking a patch on a mobile phone or any other electronic device would have a protective effect on the user. On the contrary, it may increase risk. As with metal patches on the walls, metal patches on mobile phones and other EMF-emitting devices may increase exposure due to "corner effects", and interference at unpredictable locations. Thus, they should be avoided.

Recently there was a single study reporting that the use of a chip on mobile phone had a protective role on changes in human EEG induced by the mobile phone without the chip (Henz et al., 2018). This study does not show its results in numbers but only in pictures which are not adequately explained. Moreover the study does not include any EMF-measurements of the mobile phone emissions with and without the chip, no scientific description how the chip works, and no attempt to describe a mechanism of how the chip exerts a protective effect. A request for explanations sent by us to the company that produces the chip as this was reported in this study, remained unanswered. More studies must be performed that will address all the above unresolved issues, before such products could ever be recommended for protection, especially in view of the apparent lack of any possible scientific explanation for the reported protective effect.

5. Discussion and conclusions

In the present study we explained how metals, especially ferromagnetic ones, can insulate space from external EMFs/EMR by electromagnetic coupling which is an inherent property of metals for their interaction with ambient EMFs. According to this property, we critically analyzed the effectiveness and safety of metal shielding in the form of grids, paints, garments, bed canopies, metal patches, "chips", minerals etc. offered in recent years by many private companies and individuals as EMF-shielding solutions. We provided representative EMF-shielding measurements, in order to give an estimation of how much ELF and RF EMFs are reduced by a simple sparse grid made from galvanized iron.

We underscored the fact that all these products/practices are scientifically untested, especially for long-term use, as we realized the complete lack of peer-reviewed literature verifying their effectiveness and safety. We also explained that long-term EMF-shielding, i.e. for years or for life, is very different from the short-term use of Faraday cages for experimental purposes.

We described how natural EMFs, especially atmospheric ones known as Schumann resonances, play a decisive role in the biological rhythmicity of all animals, and how disruption of this rhythmicity by attenuation of these natural EMFs is connected with health problems and even increased cancer risk (Schumann, 1952; Wever, 1970, 1973, 1979; Reinberg et al., 2007; Salgado-Delgado et al., 2011; Shanmugam et al., 2013). In view of these facts, the unofficially reported symptom relapses in EHS patients following an initial retreat after house shielding, are not surprising (Carlo, 2008).

Some supporters of metal shielding may argue that the applied shielding methods described in the present study do not significantly reduce the Schumann resonances and terrestrial EMFs as they do with higher man-made frequencies. We explained that man-made EMFs are also in the ELF band (e.g. power line or railway EMFs) or necessarily include ELFs along with the RFs. Even in the hypothetical case that some specific and carefully applied metal shielding significantly minimizes man-made EMFs, while it only slightly reduces natural atmospheric EMFs (which is not the case according to the presented measurements and Eq. (1)), even a small decrease in these vital fields when applied permanently likely constitutes a continuous weak stressor. Any weak stressor applied for a few hours or days probably will not disturb the homeostasis of an organism. But it might very well be damaging when applied continuously for years. Thus, even a small decrease in the normal intensities of the Schumann resonances - which are already very weak - would result in a weaker stimulus for internal synchronization of living organisms, with consequent higher energy consumption in order for them to maintain synchronization. This slightly higher energy consumption by an organism could thus function as a continuous mild stressor which after years may reasonably result in weakening its immune system.

We explained that permanent metal shielding should be avoided before sufficient data from long-term experiments verifying its safety are available. We also explained that metal shielding may theoretically play some beneficial role in alleviating health symptoms when applied intermittently for a few hours per day (e.g. during sleep) on the condition that interference effects or contact with the body are prevented. Long-term animal experiments with intermittent shielding should urgently be performed to ensure that internal desynchronization or other adverse health effects do not occur.

The role of "Schumann" generators producing weak pulses with the frequencies - especially the basic one of 7.8 Hz - and the waveform of the atmospheric resonances should urgently and systematically be investigated by long-term animal experiments in combination with shielding. Till then, our opinion is that, instead of even applying intermittent shielding, people should rather follow some easy practical ways to minimize EMF-exposures, first of all from their own devices, in order to protect themselves.

Exposure to the near field of any EMF-source (distance well within one wavelength of the emitted radiation for antennas smaller than the wavelength as with mobile and cordless phones or wi-fi) is much more intense (tens of times) and dangerous than exposure to the far field (Panagopoulos, 2011, 2017). The near-far field limit for antennas smaller than the wavelength is given by the equation $r = \lambda/2\pi$, (r the distance of the near-far field limit from the antenna, λ the wavelength of the emitted radiation) (Panagopoulos and Margaritis, 2010). In mobile phones the near field extends only ~2–5 cm from the device. Therefore most important is minimizing exposures from their own devices close to the sources (distances smaller than 1 m). Practical ways for this are: 1) Use strictly wire connections for internet, and domestic phones. 2) Use mobile phones at the greatest possible distance from the body by use of the loudspeaker or a wired headset with air-tube. [If the wired headset does not have air-tube, use it only occasionally.] Make only short and necessary calls, switch the phones off or put them in airplane mode when carried on the body, keep them at the greatest possible distance (at least several meters) during the day, and switch them off during sleep (Panagopoulos, 2011).

In addition, people should avoid living close to any antennas, or high voltage power lines, where studies find that health problems become statistically significant (Santini et al., 2002; Hallberg and Johansson, 2002; Draper et al., 2005; Shahbazi-Gahrouei et al., 2014). If this is not possible and shielding remains as the last solution, it should be restricted to a minimum with intermittent shielding as described.

Some may say that intermittent shielding may be inadequate to the challenges we face. We suggest shielding during sleep as a theoretically safer option than permanent space shielding or clothe shielding, as explained. This should be combined with prudent avoidance of exposures during the rest of the day by the ways we described, allowing considerable protection.

Certainly there are many cases in which people cannot have any control on the EMFs they are exposed to (especially in cases of antennas or high voltage power lines within residential areas or in people using the public transportation vehicles and exposed to EMFs from other people's devices). But unfortunately, as we explained, metal shielding does not seem to be the correct solution, except maybe for extreme cases. Everybody can at least reduce significantly the exposures from their own devices by not exposing themselves close to them. For the cases in which people have no control on the EMFs they are exposed to, the scientific community must point out the problem, and the public health authorities must set rules to protect public health.

Any application/product (and especially those intended to protect human health) must be tested by appropriate experiments conducted by experts and published in peer review international scientific journals. Any beneficial result of such experiments should then be given adequate scientific explanation in the publications. This is the only valid scientific practice. People asked to buy any products/applications should insist on seeing scientific peer-reviewed publications with biological/clinical experiments testing the specific product/application, by qualified authors with long expertise and without any conflict of interest.

Searching the peer-reviewed scientific literature, we realized the alarming dearth of scientific evidence supporting the safety and efficacy of current protecting technologies and medical approaches, in spite of the great number of products advertised in the market throughout the world. In the present study, we pointed out some of the scientific dissonance around these technologies and approaches, with the goal of providing insights towards better protection strategies for the human/animal population of the planet. Unfortunately, the only totally safe practice we can currently undoubtedly recommend is reducing the exposures by an avoidance strategy as described above.

Since metal shielding has lately been massively suggested and applied as a protective solution against man-made EMFs without proper scientific verification, we feel it is high time that this practice is picked up and examined in depth by the scientific community. We hope our present paper will initiate scientific research on the long-term effects of EMF-shielding, possibly in combination with the use of specifically constructed Schumann generators. As scientists, we feel it is our duty to discuss these issues of utmost importance for public health, elaborating as much as possible every aspect of them, and to not let people be confused or misdirected in addition to the health problems they may experience due to the increasing levels of man-made EMFs in the environment.

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References

Abdel-Rassoul, G., El-Fateh, O.A., Salem, M.A., Michael, A., Farahat, F., El-Batanouny, M., Salem, E., 2007. Neurobehavioral effects among inhabitants around mobile phone base stations. Neurotoxicology 28 (2), 434–440.

Agarwal, A., Deepinder, F., Sharma, R.K., Ranga, G., Li, J., 2008. Effect of cell phone usage on semen analysis in men attending infertility clinic: an observational study. Fertil. Steril. 89 (1), 124–128.

Agarwal, A., Desai, N.R., Makker, K., Varghese, A., Mouradi, R., Sabanegh, E., Sharma, R., 2009. Effects of radiofrequency electromagnetic waves (RF-EMW) from cellular phones on human ejaculated semen: an in vitro pilot study. Fertil. Steril. 92 (4), 1318–1325.

Alberts, B., et al., 1994. Molecular Biology of the Cell. Garland Publishing, Inc., N.Y., USA.

Alexopoulos, C.D., 1973. Electricity, Athens. (Αλεξόπουλος ΚΔ, Ηλεκτρισμός, Αθήνα 1973, Εκδόσεις Παπαζήση).

Alonso, M., Finn, E.J., 1967. Fundamental university physics. Fields and Waves. Vol. 2. Addison-Wesley, USA.

Balmori, A., 2005. Possible effects of electromagnetic fields from phone masts on a population of White Stork (Ciconia ciconia). Electromagn. Biol. Med. 24 (2), 109–119.

Balmori, A., 2006. The incidence of electromagnetic pollution on the amphibian decline: is this an important piece of the puzzle? Toxicol. Environ. Chem. 88, 287–299.

Balmori, A., 2010. Mobile phone mast effects on common frog (Rana temporaria) tadpoles: the city turned into a laboratory. Electromagn. Biol. Med. 29, 31–35.

Balser, M., Wagner, C.A., 1960. Observations of Earth-ionosphere cavity resonances. Nature 188, 638–641.

Barr, R., Llanwyn Jones, D., Rodger, C.J., 2000. ELF and VLF radio waves. J. Atmos. Sol. Terr. Phys. 62, 1689–1718.

Bawin, S.M., Adey, W.R., 1976. Sensitivity of calcium binding in cerebral tissue to weak environmental electric fields oscillating at low frequency. Proc. Natl. Acad. Sci. U.S.A. 73, 1999–2003.

Bawin, S.M., Kaczmarek, L.K., Adey, W.R., 1975. Effects of modulated VMF fields, on the central nervous system. Ann. N.Y. Acad. Sci. 247, 74–81.

Bawin, S.M., Adey, W.R., Sabbot, I.M., 1978. Ionic factors in release of $^{45}Ca^{2+}$ from chick cerebral tissue by electromagnetic fields. Proc. Natl. Acad. Sci. U.S.A. 75, 6314–6318.

Belpomme, D., Hardell, L., Belyaev, I., Burgio, E., Carpenter, D.O., 2018. Thermal and non-thermal health effects of low intensity non-ionizing radiation: an international perspective. Environ. Pollut. 242 (Pt A), 643–658. https://doi.org/10.1016/j.envpol.2018.07.019 (Epub ahead of print, Review).

Berger, H., 1929. Ueber das Elektrenkephalogramm des Menschen (On the human electroencephalogram). Archiv f. Psychiatrie u. Nervenkrankheiten 87, 527–570.

Blettner, M., Schlehofer, B., Breckenkamp, J., Kowall, B., Schmiedel, S., Reis, U., Potthoff, P., Schuz, J., Berg-Beckhoff, G., 2009. Mobile phone base stations and adverse health effects: phase 1 of a population-based, cross-sectional study in Germany. Occup. Environ. Med. 66, 118–123.

Bolshakov, M.A., Alekseev, S.I., 1992. Bursting responses of Lymnea neurons to microwave radiation. Bioelectromagnetics 13 (2), 119–129.

Buckus, R., Strukcinskien, B., Raistenskis, J., Stukas, R., Šidlauskien, A., ˇCerkauskien, R., Isopescu, D.N., Stabryla, J., Cretescu, I., 2017. A technical approach to the evaluation of radiofrequency radiation emissions from mobile telephony base stations. Int. J. Environ. Res. Public Health 2017 (14), 244.

Campisi, A., Gulino, M., Acquaviva, R., Bellia, P., Raciti, G., Grasso, R., Musumeci, F., Vanella, A., Triglia, A., 2010. Reactive oxygen species levels and DNA fragmentation on astrocytes in primary culture after acute exposure to low intensity microwave electromagnetic field. Neurosci. Lett. 473 (1), 52–55.

Carlo, G.L., 2008. Medical alert: "Aggravated symptom relapses reported after use of widely-available EMR protection products". In: Waugh, J. (Ed.), Living Safely With Electromagnetic Radiation (ISBN: 978-0-9865099-0-2). www.emfsafehome.com.

De Iuliis, G.N., Newey, R.J., King, B.V., Aitken, R.J., 2009. Mobile phone radiation induces reactive oxygen species production and DNA damage in human spermatozoa in vitro. PLoS One 4 (7), e6446.

Draper, G., Vincent, T., Kroll, M.E., Swanson, J., 2005. Childhood cancer in relation to distance from high voltage power lines in England and Wales: a case-control study. BMJ 330 (7503), 1290.

Dubrov, A.P., 1978. The Geomagnetic Field and Life - Geomagnetobiology. Plenum Press, New York.

EHS Foundation, 2013. Electromagnetic field reduction restores health of electro-sensitive people. EHS Bulletin, Suppl. 9 nr. 42, Netherlands.

Franzellitti, S., Valbonesi, P., Ciancaglini, N., Biondi, C., Contin, A., Bersani, F., Fabbri, E., 2010. Transient DNA damage induced by high-frequency electromagnetic fields (GSM 1.8 GHz) in the human trophoblast HTR-8/SVneo cell line evaluated with the alkaline comet assay. Mutat. Res. 683 (1–2), 35–42.

Frei, M., Jauchem, J., Heinmets, F., 1988. Physiological effects of 2.8 GHz radio-frequency radiation: a comparison of pulsed and continuous-wave radiation. J. Microw. Power Electromagn. Energy. 23, 2.

Gómez-Perretta, C., Navarro, E.A., Segura, J., Portolés, M., 2013. Subjective symptoms related to GSM radiation from mobile phone base stations: a cross-sectional study. BMJ Open 3 (12), e003836.

Goodman, E.M., Greenebaum, B., Marron, M.T., 1995. Effects of electromagnetic fields on molecules and cells. Int. Rev. Cytol. 158, 279–338.

Hemming, L.H., 1992. Architectural electromagnetic shielding handbook. A design and specification guide. IEEE press, New York, USA.

Hallberg, O., Johansson, O., 2002. Melanoma incidence and frequency modulation (FM) broadcasting. Arch. Environ. Health 57 (1), 32–40.

Hardell, L., Carlberg, M., Söderqvist, F., Mild, K.H., Morgan, L.L., 2007. Long-term use of cellular phones and brain tumours: increased risk associated with use for > or = 10 years. Occup. Environ. Med. 64 (9), 626–632 (Review).

Hardell, L., Carlberg, M., Hansson Mild, K., 2009. Epidemiological evidence for an association between use of wireless phones and tumor diseases. Pathophysiology 16 (2–3), 113–122.

Hardell, L., Carlberg, M., Söderqvist, F., Mild, K.H., 2013a. Pooled analysis of case-control studies on acoustic neuroma diagnosed 1997–2003 and 2007–2009 and use of mobile and cordless phones. Int. J. Oncol. 43 (4), 1036–1044.

Hardell, L., Carlberg, M., Söderqvist, F., Mild, K.H., 2013b. Case-control study of the association between malignant brain tumours diagnosed between 2007 and 2009 and mobile and cordless phone use. Int. J. Oncol. 43 (6), 1833–1845.

Havas, M., 2013. Radiation from wireless technology affects the blood, the heart, and the autonomic nervous system. Rev. Environ. Health 28 (2–3), 75–84.

Henz, D., Schöllhorn, W.I., Poeggeler, B., 2018. Mobile phone chips reduce increases in EEG brain activity induced by mobile phone-emitted electromagnetic fields. Front. Neurosci. 12, 190.

Heuser, G., Heuser, S.A., 2017. Functional brain MRI in patients complaining of electrohypersensitivity after long term exposure to electromagnetic fields. Rev. Environ. Health 32 (3), 291–299.

Höytö, A., Luukkonen, J., Juutilainen, J., Naarala, J., 2008. Proliferation, oxidative stress and cell death in cells exposed to 872 MHz radiofrequency radiation and oxidants. Radiat. Res. 170 (2), 235–243.

Huber, R., Treyer, V., Borbély, A.A., Schuderer, J., Gottselig, J.M., Landolt, H.P., Werth, E., Berthold, T., Kuster, N., Buck, A., Achermann, P., 2002. Electromagnetic fields, such

as those from mobile phones, alter regional cerebral blood flow and sleep and waking EEG. J. Sleep Res. 11, 289–295.
Hutter, H.-P., Moshammer, H., Wallner, P., Kundi, M., 2006. Subjective symptoms, sleeping problems, and cognitive performance in subjects living near mobile phone base stations. Occup. Environ. Med. 63, 307–313.
IARC, 2002. Non-ionizing Radiation, Part 1: Static and Extremely Low-frequency (ELF) Electric and Magnetic Fields. vol. 80. World Health Organization.
IARC, 2013. Non-ionizing Radiation, Part 2: Radiofrequency Electromagnetic Fields. vol. 102 (Lyon, France).
Irigaray, P., Caccamo, D., Belpomme, D., 2018a. Oxidative stress in electrohypersensitivity self-reporting patients: results of a prospective in vivo investigation with comprehensive molecular analysis. Int. J. Mol. Med. 42, 1885–1898.
Irigaray, P., Lebar, P., Belpomme, D., 2018b. How ultrasonic cerebral tomosphygmography can contribute to the diagnosis of electrohypersensitivity. J. Clin. Diagn. Res. 6 (1).
Jackson, J.D., 1975. Classical Electrodynamics. John Wiley & Sons, Inc., New York.
Johnson-Liakouris, A.J., 1998. Radiofrequency (RF) sickness in the Lilienfeld study: an effect of modulated microwaves? Arch. Environ. Health 53, 236–238.
Kato, M., 2006. Electromagnetics in Biology. Springer.
Kheifets, L., Ahlbom, A., Crespi, C.M., Draper, G., Hagihara, J., Lowenthal, R.M., Mezei, G., Oksuzyan, S., Schüz, J., Swanson, J., Tittarelli, A., Vinceti, M., Wunsch Filho, V., 2010. Pooled analysis of recent studies on magnetic fields and childhood leukaemia. Br. J. Cancer 103 (7), 1128–1135 (Erratum in: Br J Cancer. 2011, 104(1):228).
Khurana, V.G., Teo, C., Kundi, M., Hardell, L., Carlberg, M., 2009. Cell phones and brain tumors: a review including the long-term epidemiologic data. Surg. Neurol. 72 (3), 205–214.
Koenig, H.L., 1974. ELF and VLF signal properties, physical characteristics. In: Persinger, M.A. (Ed.), ELF and VLF Electromagnetic Fields. Plenum Press, New York, USA.
Kundi, M., Hutter, H.P., 2009. Mobile phone base stations-effects on wellbeing and health. Pathophysiology 16, 123–135.
Kurotchenko, S.P., Subbotina, T.I., Tuktamyshev, I.I., Tuktamyshev, ISh, Khadartsev, A.A., Yashin, A.A., 2003. Shielding effect of mineral schungite during electromagnetic irradiation of rats. Bull. Exp. Biol. Med. 136 (5), 458–459.
Lapkovskis, V., Mironovs, V., Jevmenov, I., Kasperovich, A., Myadelets, V., 2017. Multilayer material for electromagnetic field shielding and EMI pollution prevention. Agron. Res. 15 (S1), 1067–1071.
Ludwig, H.W., 1974. Electric and magnetic field strengths in the open and in shielded rooms in the ULF to LF zone. In: Persinger, M.A. (Ed.), ELF and VLF Electromagnetic Fields. Plenum Press, New York, USA.
Marshall, T.G., Rumann Heil, T.J., 2017. Electrosmog and autoimmune disease. Immunol. Res. 65, 129–135.
McCaig, C.D., Rajnicek, A.M., Song, B., Zhao, M., 2005. Controlling cell behavior electrically: current views and future potential. Physiol. Rev. 85 (3), 943–978.
McCarty, D.E., Carrubba, S., Chesson, A.L., Frilot, C., Gonzalez-Toledo, E., Marino, A.A., 2011. Electromagnetic hypersensitivity: evidence for a novel neurological syndrome. Int. J. Neurosci. 121 (12), 670–676.
Momoli, F., Siemiatycki, J., McBride, M.L., Parent, M.É., Richardson, L., Bedard, D., Platt, R., Vrijheid, M., Cardis, E., Krewski, D., 2017. Probabilistic multiple-bias modelling applied to the Canadian data from the INTERPHONE study of mobile phone use and risk of glioma, meningioma, acoustic neuroma, and parotid gland tumors. Am. J. Epidemiol. 186 (7), 885–893.
Navarro, E.A., Segura, J., Portolés, M., Gómez- Perretta, C., 2003. The microwave syndrome: a preliminary study in Spain. Electromagn. Biol. Med. 22 (2–3), 161–169.
Nieckarz, Z., Zieba, S., Kulak, A., Michalec, A., 2009. Study of the periodicities of lightning activity in three main thunderstorm centers based on Schumann resonance measurements. American Meteorological Society, Notes and Correspondence. vol. 137, pp. 4401–4409.
Nucciteli, R., 1992. Endogenous ionic currents and DC electric fields in multicellular animal tissues. Bioelectromagnetics (Suppl. 1), 147–157.
Panagopoulos, D.J., 2011. Analyzing the health impacts of modern telecommunications microwaves. In: Berhardt, L.V. (Ed.), Advances in Medicine and Biology. vol. 17. Nova Science Publishers, Inc., New York, USA.
Panagopoulos, D.J., 2013. Electromagnetic interaction between environmental fields and living systems determines health and well-being. Electromagnetic Fields: Principles, Engineering Applications and Biophysical Effects. Nova Science Publishers, New York, USA.
Panagopoulos, D.J., 2017. Mobile telephony radiation effects on insect ovarian cells. The necessity for real exposures bioactivity assessment. The key role of polarization, and the "ion forced-oscillation mechanism". In: Geddes, C.D. (Ed.), Microwave Effects on DNA and Proteins. Springer.
Panagopoulos, D.J., 2019. Comparing DNA damage induced by mobile telephony and other types of man-made electromagnetic fields. Mutat. Res. Rev. (In Print).
Panagopoulos, D.J., Balmori, A., 2017. On the biophysical mechanism of sensing atmospheric discharges by living organisms. Sci. Total Environ. 599–600 (2017), 2026–2034.
Panagopoulos, D.J., Margaritis, L.H., 2010. The identification of an intensity "window" on the bioeffects of mobile telephony radiation. Int. J. Radiat. Biol. 86 (5), 358–366.
Panagopoulos, D.J., Messini, N., Karabarbounis, A., Filippetis, A.L., Margaritis, L.H., 2000. A mechanism for action of oscillating electric fields on cells. Biochem. Biophys. Res. Commun. 272 (3), 634–640.
Panagopoulos, D.J., Karabarbounis, A., Margaritis, L.H., 2002. Mechanism for action of electromagnetic fields on cells. Biochem. Biophys. Res. Commun. 298 (1), 95–102.
Panagopoulos, D.J., Karabarbounis, A., Lioliousis, C., 2013. ELF alternating magnetic field decreases reproduction by DNA damage induction. Cell Biochem. Biophys. 67, 703–716.
Panagopoulos, D.J., Johansson, O., Carlo, G.L., 2015. Polarization: a key difference between man-made and natural electromagnetic fields, in regard to biological activity. Nat. Sci. Rep. 5, 14914. https://doi.org/10.1038/srep14914.
Penafiel, L.M., Litovitz, T., Krause, D., Desta, A., Mullins, J.M., 1997. Role of modulation on the effects of microwaves on ornithine decarboxylase activity in L929 cells. Bioelectromagnetics 18, 132–141.
Persinger, M.A., 2014. Schumann resonance frequencies found within quantitative electroencephalographic activity: implications for earth-brain interactions. Int. Lett. Chem. Phys. Astron. 11 (1), 24–32.
Presman, A.S., 1977. Electromagnetic Fields and Life. Plenum Press, New York.
Price, C., Pechony, O., Greenberg, E., 2007. Schumann resonances in lightning research. J. Light. Res. 1, 33–40.
Rea, W.J., Pan, Y., Yenyves, E.J., Sujisawa, I., Suyama, H., Samadi, N., Ross, G.H., 1991. Electromagnetic field sensitivity. J. Bioelectricity 10 (1,2), 241–256.
Reinberg, A.E., Ashkenazi, I., Smolensky, M.H., 2007. Euchronism, allochronism, and dyschronism: is internal desynchronization of human circadian rhythms a sign of illness? Chronobiol. Int. 24 (4), 553–588.
Salgado-Delgado, R., Osorio, A.T., Saderi, N., Escobar, C., 2011. Disruption of circadian rhythms: a crucial factor in the etiology of depression. Depress. Res. Treat. 839743. https://doi.org/10.1155/2011/839743.
Sangeetha, M., Purushothaman, B.M., Suresh Babu, S., 2014. Estimating cell phone signal intensity and identifying Radiation Hotspot Area for Tirunel Veli Taluk using RS and GIS. Int. J. Res. Eng. Technol. 3, 412–418.
Santini, R., Santini, P., Danze, J.M., Le Ruz, P., Seigne, M., 2002. Study of the health of people living in the vicinity of mobile phone base stations: I. Influences of distance and sex. Pathol. Biol. 50, 369–373.
Schienle, A., Stark, R., Vaitl, D., 2001. Sferics provoke changes in EEG power. Int. J. Neurosci. 107 (1–2), 87–102.
Schliephake, E., 1932. Arbeitsergebnisse auf dem Kurzwellengebiet. Dtsch. Med. Wochenschr. 58, 1235–1241.
Schumann, W.O., 1952. Uber die strahlunglosen eigenschwingungen einer leitenden Kugel, die von einer Luftschicht und einer Ionospharenh ulle umgeben ist (On the characteristic oscillations of a conducting sphere which is surrounded by an air layer and an ionospheric shell). Z. Naturforsch. 7A, 149–154.
Shahbazi-Gahrouei, D., Karbalae, M., Moradi, H.A., Baradaran-Ghahfarokhi, M., 2014. Health effects of living near mobile phone base transceiver station (BTS) antennae: a report from Isfahan, Iran. Electromagn. Biol. Med. 33, 206–210.
Shanmugam, V., Wafi, A., Al-Taweel, N., Büsselberg, D., 2013. Disruption of circadian rhythm increases the risk of cancer, metabolic syndrome and cardiovascular disease. J. Local Glob. Health Sci. 2013, 3. https://doi.org/10.5339/jlghs.2013.3.
Tesla, N., 1905. The transmission of electrical energy without wires as a means of furthering world peace. Electrical World and Engineer. vol. 7, pp. 21–24.
Tsaliovich, A., 1995. Electromagnetic coupling and shielding. Cable Shielding for Electromagnetic Compatibility. Springer.
Tsigos, C., Stefanaki, C., Lambrou, G.I., Boschiero, D., Chrousos, G.P., 2015. Stress and inflammatory biomarkers and symptoms are associated with bioimpedance measures. Eur. J. Clin. Investig. 45 (2), 126–134.
Votis, C.I., Tatsis, G., Christofilakis, V., Chronopoulos, S.K., Kostarakis, P., Tritakis, V., Repapis, C., 2018. A new portable ELF Schumann resonance receiver. Design and detailed analysis of the antenna and the analog front-end. EURASIP J. Wirel. Commun. Netw. 155.
Wang, Y., Guo, X., 2016. Meta-analysis of association between mobile phone use and glioma risk. J. Cancer Res. Ther. 12 (Supplement), C298–C300. https://doi.org/10.4103/0973-1482.200759.
Wever, R., 1970. The effects of electric fields on circadian rhythmicity in men. Life Sci. Space Res. 8, 177–187.
Wever, R., 1973. Human circadian rhythms under the influence of weak electric fields and the different aspects of these studies. Int. J. Biometeorol. 17 (3), 227–232.
Wever, R., 1974. ELF effects on human circadian rhythms. In: Persinger, M.A. (Ed.), ELF and VLF Electromagnetic Fields. Plenum Press, New York, USA.
Wever, R., 1979. The Circadian System of Man: Results of Experiments Under Temporal Isolation. Springer-Verlag.