

The incidence of electromagnetic pollution on wild mammals: A new “poison” with a slow effect on nature?

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Abstract A review on the effects of radiofrequency radiation from wireless telecommunications on living organisms and its possible impact on wild mammals are presented. Physical and technological characteristics of mobile telephone and phone masts, the scientific discoveries that are of interest in the study of their effects on the wildlife, action mechanisms on biological systems and experimental difficulties are described. Keeping in mind that electromagnetic pollution (in the microwave and radiofrequency range) is a possible source for decline of some mammal populations, it is of great importance to carry out studies on the effects of this new pollutant to wildlife. Some research types that could be useful to determine adverse health effects are proposed.

Keywords Effects on wild mammals · Electromagnetic fields · Microwaves · Mobile telecommunications · Non-thermal effects · Phone masts · Radiofrequencies

1 Introduction

Electromagnetic pollution is a type of contamination whose effects on wild mammals have not been studied. Before the 1990s, radiofrequencies were mainly from a few radio and television transmitters, located in remote areas and/or very high places. Since the introduction of wireless telecommunication in the 1990s, the rollout of phone networks has seen a massive increase in electromagnetic contamination

in cities and in the countryside (Firstenberg 1997; Galeev 2000). Greater portion of that exposure is from GSM cellular phone tower radiation (Haumann et al. 2002; Hutter et al. 2006). Also, GSM is the dominating high frequency source in the wilderness.

Multiple sources of mobile communication result in chronic exposure of a significant part of the general population and wild mammals to microwaves at non-thermal levels (Belyaev 2005). Most of the attention on possible biological effects of electromagnetic fields (EMF) has been focused on human health. Alive human organism itself supports a variety of oscillatory electrical biological activities, each characterized by a particular frequency, some of which happen to be close to those used in mobile telephony (Krstic 2005).

Man frequently uses wildlife as biological indicators to detect alterations in ecosystems and mammals are important components. Phone masts are erected indiscriminately without studies of environmental impact measuring long-term effects on habitat of several threatened species, like the Iberian Lynx (*Lynx pardina*), the Brown Bear (*Ursus arctos*), the Wolverine (*Gulo gulo*), the Eurasian Lynx (*Lynx lynx*) and the Wolf (*Canis lupus*). The objective of this review was to detail advances in knowledge on the radiofrequencies and microwaves effects to mammals and their biological mechanisms. Finally, future research directions are discussed that may help to provide a better understanding of EMF effects on vertebrate health and conservation from harmful effects by radiofrequencies exposure.

2 Sources of environmental electromagnetic radiation

In recent years, we are chronically exposed to microwaves and RFR signals from various sources, including GSM and

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UMTS/3G wireless phones and base stations, WLAN (wireless local area networks), WPAN (wireless personal area networks such as Bluetooth) and DECT (Digital Enhanced (former European) Cordless Telecommunications). These exposures are characterized by low intensities, varieties of signals and long-term durations that are comparable with a lifespan. The decrease in power density could be compensated by the increase in duration of exposure. Microwaves at frequencies within specific frequency windows (“resonances”) result in biological effects at very low intensities that are comparable with intensities from base stations and other microwave sources used in mobile communication (Lai 2005; Belyaev 2005). So far, the “dose” (accumulated absorbed energy that is measured in radiobiology as the dose rate multiplied by the exposure time) is not adopted for the exposure guidelines (EPA 2002; Lai 2005; Belyaev 2005).

3 Physical and technological characteristics of mobile telephone and phone masts

Electromagnetic radiation (EMR) has three major physical parameters: frequency, intensity and duration of exposure (Lai 2005). The radiofrequencies (RFR) occupy the range from 10 MHz to 300 GHz. Different frequencies of RFR are used in different applications. For example, the frequency range of 540–1,600 KHz is used in AM radio transmission, while 76–108 MHz is used for FM radio. Cell phone technology uses frequencies mainly between 800 MHz and 3 GHz (Lai 2005). Cellsite antennae emit a frequency of 900 or 1,800 MHz., pulsed at low frequencies, generally known as microwaves (300 MHz–300 GHz.) similar to the radar spectrum. Microwaves carry sound information by blasts or pulses of short duration, with small modulations of their frequency that are transferred between wireless phones and base stations over dozens of kilometres.

The main variable that measures these radiations is “Power Density”, measure in Watts per square metre (W/m^2) or in Microwatts per square centimetre ($\mu\text{W/cm}^2$) expressing radiant power that impacts perpendicularly to a surface, divided by the surface area; and “Electric Field Intensity” (measured in Volts per metre: V/m), a vectorial magnitude to the force exercised on a electric loaded particle, independently of their position in space. The cellsite ordinarily has three sectors, with three antennae that cover an angle of 120° each (Santini et al. 2000; Hyland 2000, 2001; Navarro et al. 2003; Hutter et al. 2006). For a concrete address with relationship to an antenna, the power density at a point varies inversely proportional to the square of the distance to the source. Though EMR have many and varied outputs, at a distance of 50 m, the power density is about $10 \mu\text{W/cm}^2$ (Santini et al. 2000), while at distances of 100 m at ground level, it measures

above $1 \mu\text{W/cm}^2$ (Personal Observation). Between 150 and 200 m, the power density of the main lobe near the ground is typically some tenth of $1 \mu\text{W/cm}^2$ (Hyland 2000).

4 Importance of environmental electromagnetic fields for wild mammals

Current scientific evidence indicates that prolonged exposure to EMFs, at levels that can be encountered in the environment, may affect immune system function by affecting biological processes (Chou et al. 1992; Novoselova and Fesenko 1998; Galeev 2000). A stressed immune system may increase the susceptibility to infectious diseases, bacteria, viruses and parasites (Fernie and Bird 2001). Animals exposed to EMF can suffer a deterioration of health and changes in behaviour that disappeared when moving away from the antennas (Marks et al. 1995; Löscher and Käs 1998).

Bat activity is significantly reduced in habitats exposed to an electromagnetic field (EMF) strength of greater than 2 V/m . Electromagnetic radiation can exert an aversive behavioural response in bats (Nicholls and Racey 2007). Rats spent more time in the halves of shuttle boxes that were shielded from irradiation by 1.2 GHz microwaves. The average power density was about 0.6 mW/cm^2 . Data revealed that rats avoided the pulsed energy, but not the continuous energy, and less than 0.4 mW/cm^2 average power density was needed to produce aversion (Frey and Feld 1975). Navakatikian and Tomashevskaya (1994) described a complex series of experiments in which they observed disruption of rat behaviour (active avoidance) from radiofrequency radiation. Behavioural disruption was observed at a power density as low as 0.1 mW/cm^2 . Mice in experimental group exposed to microwave radiation expressed visible individual panic reaction, disorientation and greater degree of anxiety. In control group, these deviations of behaviour were not register and all animals show compact collective defence reaction (Krstic 2005).

In the town of Casavieja (Ávila, Spain), a telephony antenna was installed that had been in operation for about 5 years. Then some farmers began blaming the antenna for miscarriages in many pigs, 50–100 m from the antenna (outskirts of the town). The topic became so bad that the town council decided to disassemble the antenna. It was removed in the spring 2005. From that moment onwards, the problems finished (C. Lumbreras personal communication). Also in humans, magnetic field exposures above 2.0 mG were positively associated with miscarriage risk (Lee et al. 2002).

In pregnant rats exposed to 27.12 MHz continuous waves at an intensity of $100 \mu\text{W/cm}^2$ during different periods of pregnancy, half the pregnancies miscarried

before the 20th day of gestation, compared to only a 6% miscarriage rate in unexposed controls, and 38% of the viable foetuses had incomplete cranial ossification, compared to less than 6% of the controls. Findings included a considerable increase in the percentage of total reabsorptions (post-implantation losses consequent to RF radiation exposure in the first post-implantation stage). Reduced body weight increase in the exposed dams reflected a negative influence on their health. It seems that the irradiation time plays an important role in inducing specific effects consequent to radiofrequency radiation exposure (Tofani et al. 1986). There was also a change in the sex ratio, with more males born to rats that had been irradiated from the time of conception (Firstenberg 1997). Moorhouse and Macdonald (2005) find a substantial decline in female water voles numbers in the radio-collared population, apparently resulting from a male skew in the sex ratios of offspring born to this population. Recruits to the *radio-tracked* population were skewed heavily in favour of males (43:13). This suggests that radio-collaring of females caused male-skewed sex ratios.

A Greek study (Magras and Xenos 1997) reports a progressive drop in the number of births of rodents. The mice exposed to $0.168 \mu\text{W}/\text{cm}^2$ become sterile after five generations, while those exposed to $1.053 \mu\text{W}/\text{cm}^2$ became sterile after only three generations. The interaction seems to take place through the central nervous system more than on the reproductive gland directly. At the moment, this power density is present in many places and in the countryside several hundred metres surrounding phone masts. Other studies find a decrease in fertility, increase in deaths after birth in rats and dystrophic changes in their reproductive organs (Nikolaevich et al. 2001).

Prolonged exposure may have negative effects on animal sperm motility characteristics and reproductive capacity (Dasdag et al. 1999; Davoudi et al. 2002; Fejes et al. 2005). Also, EMF and microwaves affect reproductive success in birds (Doherty and Grubb 1996; Fernie et al. 2000a, b; Balmori 2005; Balmori and Hallberg 2007).

Microwaves used in cellphones produce a non-thermal response in several types of neurons of the nervous system in birds (Beason-Held and Semm 2002) and can affect the blood–brain barrier that lets toxic substances pass through from the blood to the brain, observed in rats (Salford et al. 2003).

Microwave radiation at 1.5 GHz frequency, pulsing 16 ms duration and $0.3 \text{ mW}/\text{cm}^2$ power density, in sessions of 30 min/day over 1 month produced anxiety and alarm in rabbits (Grigoriev et al. 1995). Electromagnetic radiation caused a modification of sleep and alteration of the cerebral electric response (EEG) (Mann and Roschke 1996; Kramarenko and Tan 2003; Marino et al. 2003). Children exposed had less developed memory and

attention, their reaction time was slower and their neuromuscular apparatus endurance was decreased (Kolodynski and Kolodynska 1996). The microwave radiation of the phone masts favours the aggressiveness in people and animals like dogs (personal observation).

In monkeys, central nervous system excitability was influenced by applying fields focussed on the cerebellum. Frequencies below 50 Hz influenced spontaneous behaviour of the monkey. The technical possibility of using magnetic fields as non-invasive methodology to produce activation of the central nervous system with different effects in different brain structures exists (Delgado 1985). In the rat brain, Lai et al. (1989) found that microwaves activate endogenous opioid neurotransmitters with morphine-like properties, which are involved in many important physiological and behavioural functions revealing long-term effects such as pain perception and motivation. The mice in experimental group exposed to microwave radiation showed less weight gain compared to control after 2 months. Meanwhile, the amount of used food was similar in both groups (Krstic 2005).

5 Experimental difficulties

One of the well-known effects of microwaves is their capacity to excite water molecules and other components in food, elevating their temperature. The resulting heating level depends on radiation intensity and exposure time. At a power density above $500 \mu\text{W}/\text{cm}^2$, heating effects take place, below that level, the effects are non-thermal.

Animals are sensitive complex electrochemical systems that communicate with their environment through electrical impulses. In cellular membranes and body fluids, ionic currents and electrical potential exist (Heredia-Rojas et al. 2003). Radiofrequencies have lower penetration than low frequency EMF into biological tissues, but have the potential to induce much higher electric field voltages in biological tissues (Di Carlo et al. 2002). Living organisms are exposed to variable levels of radiofrequency EMF, according to (1) distance to phone masts, (2) presence of metallic structures able to reflect or obstruct the waves (buildings or other obstacles), (3) number of phone masts and (4) orientation and position (Santini et al. 2000).

Experiments to study effects of electromagnetic radiation on living organisms are complex, since a high number of variables exist that need to be controlled. Microwave effects on a number of physical parameters and biological variables may result in misleading conclusions regarding the reproducibility of the non-thermal microwaves effects (Belyaev 2005). The fundamental question is how microwaves at low intensities affect living systems? Most probably, the physical mechanisms of the non-thermal

microwave effects must be based on a quantum-mechanical approach and physics of non-equilibrium and non-linear systems (Belyaev 2005).

Numerous experimental data have provided strong evidence for non-thermal microwave effects and have also indicated several regularities in these effects: dependence of frequency within specific frequency windows of “resonance-type”; dependence on modulation and polarization; dependence on intensity within specific intensity windows, including super-low power density comparable with intensities from base stations/masts (Adey 1981; Hyland 2000; Lai 2005; Belyaev 2005). Some studies demonstrated different microwave effects depending on wavelength in the range of millimetre, centimetre or metre (Kemerov et al. 1999; Nikolaevich et al. 2001).

Duration of exposure may be not less important than power density. Biological effects resulting from electromagnetic field radiation might depend on the dose (duration of exposure), which indicates long-term accumulative effects (Adey 1996; Galeev 2000; Lai 2005). The guidelines only consider short-term exposure effect. Effects of long-term exposure, modulation and other propagation characteristics are not considered (Lai 2005).

6 Biological effects and action mechanisms

It has been documented that radiofrequencies induce biological effects on molecules (Daniells et al. 1998; De Pomerai et al. 2000; Goodman and Blank 2002; Weisbrot et al. 2003) and changes on intracellular ionic concentration (Dutta et al. 1989; Paulraj et al. 1999). “In vitro” simple exposure of an aqueous solution of acetyl cholinesterase to cellular phone emission alters its enzymatic activity. Radio frequency radiations irreversibly affect the structural and biochemical characteristics of that important central nervous system enzyme (Barteri et al. 2005).

The radiofrequency and microwaves from mobile telephony can cause genotoxic effects (Garaj-Vrhovac et al. 1991; Lai and Singh 1995; Balode 1996; Belyaev et al. 2004; Demsia et al. 2004; Reflex 2004; Diem et al. 2005; Gandhi and Singh 2005). The increases in cytological abnormalities imply long-term detrimental effects since chromosomal damage is a mechanism relevant to the causation of birth defects and cancer (Gandhi and Singh 2005).

Electromagnetic radiation causes the activation of cellular stress responses, presumably reflecting increased levels of protein structural alteration, this increased oxidative stress lead to significant disorders of function and structure of brain and liver cell in mice (Krstic 2005). A link between electromagnetic field exposure and higher oxidative stress levels in male American Kestrels exists. Higher levels of oxidative stress appear to be a major

contributor to aging, neurodegenerative diseases, immune system disorders and cancer in mammals (Ferne and Bird 2001).

Bioelectric fields have long been suspected to play a causal role in embryonic development. Alteration of the electrical field may disrupt the chemical gradient and signals received by embryo cells. It appears that in some manner, cells sense their position in an electrical field and respond appropriately. The disruption of this field alters their response. Endogenous current patterns are often correlated with a specific morphogenetic events (Hotary and Robinson 1992).

In birds, a study shows a statistically significant high mortality rate of chicken embryos subjected to radiation from a cellphone, compared to the control group (Grigoriev 2003). EMF exposure affected reproductive success of kestrels (*Falco sparverius*), increasing fertility, egg size, embryonic development and fledging success but reducing hatching success (Ferne et al. 2000a, b). Pulsed magnetic fields can have a significant influence on the development and incidence of abnormalities in chicken embryos. In five of six laboratories, more exposed embryos exhibited structural anomalies than did controls. When data from all six laboratories are pooled, the difference in incidence of abnormalities in exposed embryos and that of controls are highly significant. Malformations in the nervous system and heart and embryo delayed in growth are observed in this study. The period during which the embryo is most sensitive to exposure is the first 24 h of incubation (Berman et al. 1990). Microwaves from phone masts are interfering with White Stork reproduction in nesting sites (Balmori 2005).

Several studies addressed behaviour and teratology in young birds exposed to EMF (Ferne et al. 2000a, b; Ferne and Reynolds 2005; Balmori 2005; Balmori and Hallberg 2007). Most studies indicate that electromagnetic field exposure of birds generally changes, but not always consistently in effect or in direction, their behaviour, reproductive success, growth and development, physiology and endocrinology and oxidative stress (Ferne and Reynolds 2005). These results can be explained by EMF affecting the birds’ response to the photoperiod as indicated by altered melatonin levels (Ferne and Bird 1999).

Some organs or systems like the brain, heart and nervous system are especially vulnerable.

Existing results indicate changes in the response characteristics of a biological system with repeated exposure, suggesting that the effects are not “forgotten” after each episode of exposure. There is an indication that an animal becomes more sensitive to the radiation after long-term exposure that can be quite different from short-term exposure (Lai 2005). Under similar exposure conditions, a short-term, high-intensity exposure can produce the same effect as

a long-term, low-intensity exposure (Lai 2005; Belyaev 2005). This suggests that RFR effects can accumulate over time and can have very significant implications for mammals exposed to radiofrequencies in the environment (Magras and Xenos 1997; Lai 2005; Balmori 2005).

Modulated and pulsed radiofrequencies seem to be more effective in producing effects (Lai 2005; Belyaev 2005). Pulsed waves (in blasts), as well as certain low frequency modulations, exert greater biological activity (Úbeda et al. 1994; Grigoriev 1996; Hyland 2001; Nikolaevich et al. 2001). This observation is important because cell phone radiation is modulated at low frequencies (Hyland 2000; Lai 2005). The low intensity pulsed microwave radiation from cell sites produce subtle non-thermal influences in living organisms, because this radiation is able to produce biological responses by the microwave carrier and by the low frequency of pulses from GSM system.

Intermittent exposure showed a stronger effect than continuous exposure (Belyaev 2005). In rats brief, intermittent exposure to low-frequency EM fields during the critical prenatal period for neurobehavioral sex differentiation can demasculinize male scent marking behaviour and increase accessory sex organ weights in adulthood (McGivern et al. 1990). Epidemiological studies find that repeated EMF exposure enhanced probability of cancer (Hallberg and Johansson 2004; Hardell et al. 2006) and Alzheimer's disease (Sobel et al. 1996).

Available data suggest dependencies of genotype, gender, physiological and individual factors on the non-thermal microwave effects (Lai 2005; Belyaev 2005). Genomic differences can influence cellular responses to GSM microwaves. Data analysis highlighted a wide inter-individual variability in the response, which was replicated in further experiments (Belyaev 2005). An increase in the mortality (Youbicier-Simo and Bastide 1999) and appearance of morphological abnormalities, especially of the neural tube (Úbeda et al. 1983, 1994; Farrel et al. 1997) has been recorded in chicken embryos exposed to pulsed magnetic fields, with different susceptibility among individuals probably for genetic reasons. It is possible that each species and each individual show different susceptibility to radiation, since vulnerability depends on genetic tendency, and the physiological and neurological state of the irradiated organism (Farrel et al. 1997; Mevissen and Häubler 1998; Flipo et al. 1998; Fernie et al. 2000a, b; Hyland 2001; Fedrowitz et al. 2004; Fernie and Reynolds 2005). Different susceptibility of each species has also been proven in wild birds exposed to EMF from high-voltage powerlines (Doherty and Grubb 1996).

Microwaves effects depend on the physiological conditions. Radical scavengers/antioxidants might be involved in effects of microwaves (Belyaev 2005). Long-terms

continuous, or daily repeated EMF exposure can induce cellular stress responses at non-thermal power levels that lead to an accumulation of DNA errors and to the inhibition of cell apoptosis and cause increased permeability of blood–brain barrier due to stabilization of endothelial cell stress fibres. Repeated occurrence of these events over a long period of time (years) could become a health hazard due to a possible accumulation of brain tissue damage. These findings have important implications with regards to potential dangers from prolonged and repeated exposure to non-ionizing radiation in the environment (Di Carlo et al. 2002; Leszczynski et al. 2002).

7 Proposed research

To demonstrate the conclusive effect of microwave radiation on mammals, it is necessary to approach research with a control (non-exposed) and an experimental group. This methodological position is complicated at present due to the ubiquity of these radiations (Grefner et al. 1998; Belyaev 2005). Studies that try to correlate populational evolution or the presence or absence of wild mammals with measurements of EMF from radiofrequencies will be of great interest. Field investigations of urban park populations and phone masts surrounding territories need to be a high priority. A radius of 1 km laid out in concentric circumferences at intermediate distances may be useful to investigate differential results among areas, depending on their vicinity and corresponding levels of electromagnetic radiation. Laboratory studies on mammals exposed to pulsed and modulated microwaves would also be of great interest.

Bioelectromagnetics is historically the frontier among several far away disciplines. Controversy is frequent when scientists recognize serious effects on health and the environment that cause high economic losses. The ICNIRP safety standards, which are based on thermal effects in acute exposures, can never protect from the chronic exposures to non-thermal microwaves from mobile communication (Belyaev 2005). Independent investigators state the necessity of a drastic reduction of emitted power levels on people and the ecosystems and it is technically viable although more expensive for industry (De Pomerai et al. 2000; Hyland 2001; Balmori 2005). Areas of continuous use should never exist at the height of the antennas nor inside the beam or within a radius of several hundreds metres. The restriction to exposure of fauna presents special complexity; the main reason for the drastic reduction in the emission power of antennae is presented as the only viable and effective solution to prevent effects.

8 Conclusions

In wilderness, chronic exposure to low-level radiation can have long-term effects (Adey 1996; Magras and Xenos 1997; Everaert and Bauwens 2007). The impact of radiation on populations of invertebrate prey and plants may cause a deterioration of the ecosystem (Carpenter and Livstone 1971; Balodis et al. 1996; Selga and Selga 1996; Weisbrot et al. 2003; Balmori 2004, 2006a, b; Panagopoulos et al. 2004; Stever et al. 2005). EMF is a form of environmental pollution that may hurt wild mammals.

There is a risk that phone masts located in mammals living areas are irradiating in a continuous way to some endangered species such as the brown bear (*Ursus arctos*) or the Iberian lynx (*Lynx pardina*). These species could suffer long-term effects from reduction of their natural defences and slowly deteriorating health or even reducing their useful territory through habitat deterioration. Specific studies are necessary to value these effects. Data about the effects of microwaves at super low intensities and the significant role of duration of exposure in these effects along with data showing that adverse effects of non-thermal microwaves from GSM/UMTS mobile phones depend on carrier frequency and type of the microwave signal, suggest that microwaves from basestations/phone masts can produce adverse effects from prolonged durations of exposure and encourage to carry out in vitro studies using real signals from base stations/masts (Belyaev 2005). Since the increase in electromagnetic field by reflective boundaries and the additivity of sources has not been recognized yet, further detailed studies on various situations and development of appropriate regulations are required (Hondou 2002).

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