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The incidence of electromagnetic pollution on the amphibian decline: Is this an important piece of the puzzle?

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Abstract
A bibliographical review on the possible effects of radiofrequency radiation (RFR) from wireless telecommunications on living organisms and its impact on amphibians is presented. The technical characteristics of this new technology and the scientific discoveries that are of interest in the study of their effects on wild fauna and amphibians are described. Electromagnetic pollution (in the microwave and in the radiofrequency range) is a possible cause for deformations and decline of some amphibian populations. Keeping in mind that amphibians are reliable bio-indicators, it is of great importance to carry out studies on the effects of this new type of contamination. Finally, some methodologies that could be useful to determine the adverse health effects are proposed.

Keywords: *Athermal effects, electromagnetic pollution, effects on amphibians, microwaves, phone masts*

Introduction

Amphibians are important components of the ecosystem and reliable bio-indicators; their moist skin, free of flakes, hair or feathers, is highly permeable to water chemicals (particularly larvae) and air pollutants (especially adults). Amphibian eggs are also directly exposed to chemicals and radiation. These characteristics make amphibians especially sensitive to environmental conditions, changes of temperature, precipitation or ultraviolet (UV) radiation and reliable monitors of local conditions [1].

A recent report from the International Union for Conservation of Nature (IUCN), prepared by 500 scientists from 60 countries, analyzed populations of 5743 amphibian

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species in the world and concluded that 1856 (32%) of them were considered threatened of extinction. Nine species have become extinct since 1980 and another 113 have not been observed in the recent years, and probably are also extinct [2]. The results demonstrate that amphibians are far more threatened than either birds or mammals, and the factors causing 'enigmatic' declines are driving the species toward extinction particularly rapidly. Unless these declines are quickly understood and reversed, hundreds of amphibian species can be expected to become extinct over the next few decades [3]. The disappearance of amphibians together with other organisms is a part of the global biodiversity crisis [4,5].

An associated phenomenon is the appearance of large numbers of deformed amphibians, with absent or extra limbs [5]. From 1995, at least 60 different species were affected with a high incidence of deformities, with several species affected in one place, in 46 states of United States and in regions of Japan, Canada, and several European countries [5,6]. The problem seems to have become more prevalent, with deformity rates of up to 25% in some populations, which is significantly higher than in previous decades [6].

The problem of deformities is complex because it is related to water quality, physiology, development, anatomy, and ecology [5]. The reduction in populations and the increase in deformities are a warning of serious environmental degradation [5].

Evidence exists that several populational declines are probably the result of complex interactions among several biotic and abiotic factors [1,4,7,8]. The proposed explanations are an increase of ultraviolet radiation (UV-B)[1,5,9–14]; chemical pollutants (pesticides, herbicides, fungicides, fertilizers, etc.) [5,15]; pathogen and parasites [1,6,16], destruction and alteration of habitat, changes in meteorological patterns (climatic change) [4,17], and introduced species [1,5].

The amphibian population declines are also occurring in relatively pristine places such as National Parks, or rural areas far from urban centers [3,14]. Humans and other animals can also be affected by the same environmental factors that damage amphibians [6].

A type of contamination whose effects on amphibians have not been studied up to now, is the electromagnetic pollution, especially microwaves and radiofrequencies from mobile telecommunications and radio station transmitters that will be discussed in this review. 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 the electromagnetic contamination in cities and in the wilderness [18,19]. At the moment, new types of antennas are being investigated to reduce the power needed to establish communication [20,21]. Recently, there has also been an increase of other wireless transmitters (radio or television stations).

The objective of this review is to detail advances in the knowledge of biological mechanisms and effects from radiofrequencies and microwaves on animals, and some considerations are made on its possible relationship with deformations and the population decline of amphibians.

Main causes of populational decline and appearance of deformations in amphibian populations

Ultraviolet radiation

UV-B radiation (1) induces mutations and cellular death, (2) weakens the immune system, (3) reduces growth, and (4) induces several types of damage, like malformations of the limbs, body, and eyes [1,5,12,14]. Not all the species respond in the same way [14]. Embryos with higher photolyase levels (DNA photorepair enzyme) are more resistant to UV-B radiation [11,12].

The eggs of some of the amphibian species experienced high mortality that may contribute to the populational declines [9]. UV acts in conjunction with other agents like pesticides to induce defects in the development [10]. UV also decreases defense mechanisms against illnesses making individuals more susceptible to pathogen and parasites, affecting normal development and increasing mortality that consequently impacts on the decline of some populations [10]. The egg mass protected from UV-B radiation have significantly more hatching, less deformities, and develop more quickly [10].

Synergy between a pathogenic fungus and UV-B radiation increased mortality among amphibian embryos [12]. The synergy may occur when developing amphibians have reduced ability to respond to a stressor in the presence of another stressor. For example, contamination exerts more deleterious effects with UV-B [1]. Animals use molecular and physiologic mechanisms and certain behaviors [22] to limit their exposure to UV-B and repair from UV-B damage [14].

Although cellular repair mechanisms of several species are not effective in the presence of persistent increase in UV-B radiation levels [14], amphibians are relatively resistant to this radiation if they can repair the damage effectively [14]. In some species, photoreactivation is the most important repair mechanism of UV-damaged DNA [9]. Heat shock proteins may also play a role in protecting cells from UV-B damage, since they prevent the denaturation of proteins during exposure to environmental stress [14].

Chemical pollutants

Chemical pollutants appear in areas where pesticides and fertilizers are applied extensively and produce mortality and deformities in amphibians. Although on a broad scale, no correlation between pesticide contamination and amphibian deformities was found, pesticides cannot be completely ruled out as causal agents [5].

Pathogens and parasites

Three pathogens received attention recently for having produced an amphibian populational decline in some areas: *Batrachochytrium denderobatidis, Saprolegnia ferax,* and an iridovirus (*Ambystoma tigrinum virus*) [1]. The parasite *Ribeiroia ondatrae* is an important source of malformations of amphibian extremities in western USA [16]. Larvae with malformations experience higher mortality before and during metamorphosis than the normal ones. The relevance of infection by *Ribeiroia* and the influence of habitat alteration on the pathology and biological cycle of this trematode, requires further investigation [16]. In relative pristine environments, the incidence of snails infected with *Ribeiroia* is low, but the habitat alteration can increase the rate of infestation [16]. Infection of amphibian larvae by the trematode *R. ondatrae* may represent a threat to amphibians or species in decline. Although deformities can be the cause of declines in some places, numerous populations of amphibians have greatly declined in the absence of any deformity, for which there must be other factors [6].

Climatic change

Climatic change influences breeding patterns of certain organisms which affect their populational structure and may be reflected in the populational declines of very sensitive species such as amphibians. The pattern found up to now in the published studies is that some anurans of temperate areas show an early reproduction tendency [17]. Climate-induced reductions in water depth at egg-laying sites produced high embryo mortality by increasing their exposure to UV-B radiation which is more worrying than the reduction in ozone layer. Climate also increases their vulnerability to *S. ferax* [4].

Physical and technological characteristics of mobile telephone

Electromagnetic radiation (EMR) transmits small packages of energy denominated photons [23]. The radiofrequencies occupy the range from 10 MHz to 300 GHz. Cellsite antennae emit a frequency of 900 or 1800 MHz, pulsed at low frequencies, generally known as microwaves (300 MHz–300 GHz). 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' (measured in $W\,m^{-2}$, or $\mu W\,cm^{-2}$) expressing radiant power that impacts perpendicularly to a surface, divided by the surface area; and 'electric field intensity' (measured in $V\,m^{-1}$), a vectorial magnitude to the force exercised on a electric loaded particle, independent of their position in space.

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 $10\,\mu W\,cm^{-2}$ [24], while at distances of 100 m at ground level it measures above $1\,\mu W\,cm^{-2}$ (pers. obs.). Between 150 and 200 m, the power density of the main lobe near the ground is typically some tenth of $1\,\mu W\,cm^{-2}$ [25].

Experimental difficulties

Experiments that study the effects of EMR on living organisms are complex, since a high number of variables exist that need to be controlled. Microwave radiation produces different effects depending on certain methodological positions such as frequency, power, modulation, pulses, time of exposure, etc. [26–28]. Some studies demonstrated different microwave effects depending on the wavelength in the range of mm, cm or m [28,29]. The dose–response relationships (of non-thermal effects), are not simple to establish since they present a non-linear relationship [30–32].

Pulsed waves (in blasts), as well as certain low frequency modulations exert greater biological activity [26,28,31,33]. These radiations also have accumulative effects that depend on the duration of exposure [19,34,35]. It is possible that each species and each individual, show different susceptibility to radiations, since the vulnerability depends on the genetic tendency, and the physiologic and the neurological state of the irradiated organism [31,36–41].

Effects and action mechanisms on biological systems

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 the radiation intensity and the exposure time. At a power density above $500\,\mu W\,cm^{-2}$

(microwave ovens) heating effects take place, below that level the effects are 'athermal non-heating'.

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 [42]. Electromagnetic fields (EMFs) generated in biological structures, are characterized by certain specific frequencies. It is possible a frequency-specific, non-thermal electromagnetic influence, of an informational nature exists [25,31,43]. Some organs or systems like the brain, heart, and nervous system are especially vulnerable.

The wave systems have properties such as the frequency, which affect resonance capacity of living organisms to absorb the energy of an electromagnetic field [25]. Electromagnetic fields induce biological effects at "windows of frequency" (window effect) [44]. Living organisms are exposed to variable levels of radiofrequency electromagnetic fields, according to (1) distance to phone masts, (2) presence of metallic structures which are able to reflect or obstruct the waves (buildings or other obstacles), (3) number of phone masts, and (4) orientation and position [24].

Microwaves emitted by phone antennae affect organisms living in their vicinities, like vertebrate [45–47], insects [48–55], vegetables [56–58], and humans [25,31,59–63]. Small organisms are especially vulnerable: size approach to resonance frequency and thinner skull, facilitates an elevated penetration of radiation into the brain [24,31,64]. In a recent study carried out with bees in Germany, only few irradiated bees returned to the beehive and required more time to reach the hive. The weight of honeycombs is also smaller in the bees that were irradiated [54].

The microwave effects were investigated in a variety of living organisms, but the results found in vertebrates have special interest to amphibians. For more than 30 years, there is growing evidence on the existence of athermal effects on birds [65,66]. The exposed animals suffer a deterioration of health in the vicinity of phone masts [67,68]. Rats spent more time in the halves of shuttle boxes that were shielded from illumination by 1.2 GHz microwaves. The average power density was about $0.6\,\mathrm{mW\,cm^{-2}}$. Data revealed that rats avoided the pulsed energy, but not the continuous energy, and less than $0.4\,\mathrm{mW\,cm^{-2}}$ average power density was needed to produce aversion [69]. Navakatikian and Tomashevskaya [70] described a complex series of experiments in which they observed disruption of a rat behavior (active avoidance) by radiofrequency radiation (RFR). Behavioral disruption was observed at $0.1\,\mathrm{mW\,cm^{-2}}$ ($0.027\,\mathrm{W\,kg^{-1}}$) power density.

It has been documented that the radiofrequencies induce biological effects on biomolecules [27,51,71] that include changes in intracellular ionic concentration [72,73], cellular proliferation [74], interferences with immune system [19,75,76], effects on animals reproductive capacity [77,78], effects on stress hormones [79], in intrauterine development [80], genotoxic effects [81–87], effects on the nervous system [32,88–92], the circulatory system [93,94], and a decline in the number of births [47,95]. Firstenberg [18] proposed a connection between EMR, deformations, and the worldwide decline and extinction of amphibians.

Evidence that electromagnetic contamination may be responsible for the appearance of deformities and decline of amphibians

Some athermal effects of EMR on amphibians have been well known for more than 35 years [96,97]. The radiation of frogs with $30–60\,\mu\mathrm{W\,cm^{-2}}$ produced a change in the heart rhythm, probably due to the nervous system activation (Levitina, 1966 cited in [96]). When toad hearts were irradiated with pulses of 1425 MHz at a power density of $0.6\,\mu W\,cm^{-2}$, an increase in the heart rate and arrhythmia were observed [96]. Radiofrequency burst-type dilated arterioles were observed on the web of the anaesthetized frog (*Xenopus laevis*) by a athermal non-heating mechanism [93].

The exposure to magnetic fields on two species of amphibians induced deformities [48].

Frog tadpoles (*Rana temporaria*) developed under electromagnetic field (50 Hz, $260\,A\,m^{-1}$) have increased mortality. Experimental tadpoles developed more slowly and less synchronously than control tadpoles, remain at the early stages for a longer time. Tadpoles developed allergies and EMF causes changes in the blood counts [98].

Amphibians can be specially sensitive: thresholds of an overt avoidance response to weak electrical field stimuli down to $0.01\,V\,m^{-1}$ were found in *Proteus anguinus* and $0.2\,V\,m^{-1}$ in *Euproctus asper* at 20–30 Hz, but sensitivity covered a total frequency range of below 0.1 Hz to 1–2 kHz [99].

Deformities in nature

Ultraviolet radiation, UV-B. UV-B radiations produce deformities in amphibian embryos that go from lateral flexure of the tail to abnormal skin, eye damage, and lower survival rate [6,10]. However, numerous experiments carried out did not provide evidence that this exposure induces all types of deformities observed in nature, nor the appearance of extra limbs, one of the most frequent deformities noted [5,6]. On the other hand, most of the deformations for UV-B radiation occur in the legs or in reduction of the number of bilateral fingers. However, in the wild, amphibians exhibit a wide diversity of aberrations that are limited to only one side of the body, including problems in the skin, loss of legs, and twisted internal organs, reasons for which it was considered that this radiation is not the only source [5]. Similar abnormalities found in the wild and not induced by UV-B radiation have been obtained in laboratory studies, by exposing amphibian larvae to magnetic fields [48]. A similarity exists in the deformations of amphibians observed by Levengood [48] and Blaustein and Johnson [5]. Several studies addressed behavior and teratology in young birds exposed to electromagnetic fields [39,41]. Typical abnormalities include malformation of the neural tube and abnormal twisting of the chicken embryo. The electric currents are believed to have a significant role in the control of development and it is also possible that external EMR could influence these control systems [100]. The appearance of morphological abnormalities influenced by pulsed electromagnetic fields during embryogenesis in chickens [33,101] are similar to those produced by ultraviolet radiation [36]. The pulses are in fact a characteristic of mobile telephone radiations that have increased from 1995, when a marked rise in deformations started. Several experimental studies point out that the exposure to UV-B produced deferred effects (early exposure causes delayed effects in later stages) [1]. The exposure to electromagnetic fields also induces delayed effects and the tadpoles are the same as the control until the beginning of metamorphosis. The extra limbs and blistering were induced during the gastrula stage of the development which appeared to be the most sensitive stage [48]. The early *Rana pipiens* embryonic development was also inhibited by magnetic fields [97]. In rats, brief intermittent exposure to low-frequency EMFs during the critical prenatal period for neurobehavioral sex differentiation can demasculinize male scent marking behavior and increase accessory sex organ weights in adulthood [102]. Biological effects resulting from EMR field exposures might depend on the dose (e.g. duration of exposure). Short-term exposures up-regulate cell repair mechanisms, whereas long-term exposures appear to down-regulate protective responses to UV radiation [103].

Parasites. The parasite *R. ondatrae* is an important and extensive cause of malformations in amphibian extremities in western USA [16]. Tadpoles with malformations experience higher mortality than the normal ones before and during metamorphosis. The *Ribeiroia* infection represents a threat for amphibian populations that are in decline. However, with a growing volume of data based on the experimental evidence, the infection from parasites does not seem to be the cause of all the malformations on limbs, since in some places with the presence of deformations, the parasite *R. ondatrae* was absent [5]. Further certain deformities like the absence of eyes, limbs, and twisted internal organs was not induced by the parasite [5].

In a laboratory study, eggs and embryos of *Rana sylvatica* and *Ambystoma maculatum* were exposed to magnetic fields at several development stages. A brief treatment of the early embryo produced several types of abnormalities: microcephalia, scoliosis, edema, and retarded growth [48]. Several of the treated tadpoles developed severe leg malformations and extra legs, as well as a pronounced alteration of histogenesis which took the form of subepidermal blistering and edema [48]. In chick embryos exposed to pulsed EMR a potent teratogenic effect was observed: microphthalmia, abnormal trunkal torsion, and malformations on the neural tube [33,36,101,104]. One of the possible reasons for these deformities appearing more often [5], may be due to wireless telecommunications and exponential increase of electromagnetic contamination.

Bioelectric fields have long been suspected to play a causal role in embryonic development. The electrical field may directly affect the differentiation of some tail structures, in particular those derived from the tail bud. 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 such a limb bud formation. The most common defect in chick embryos experimental group was in tail development. Internally, tail structures (neural tube, notochord, and somites) were frequently absent or malformed. Defects in limb bud and head development were also found in experimentally treated chick embryos, but less often than the tail defects [105]. Amphibians can be especially sensitive because their skin is always moist, and they live close to, or in water, which conducts electricity easily.

Populations' decline

Deformities found in nature can directly affect embryonic mortality and survival after hatching [10]. It seems interactions that exist among UV-B radiation and additional factors contribute to embryo mortality [9]. Water pollution and excessive ultraviolet radiation act jointly, producing specific problems and alter the immune system, making amphibians more vulnerable to parasitic invasions and pathogen infections [6,8,12,14]. It is proposed that there exists a possible relationship between the decline of amphibians and exponential increase of electromagnetic pollution. Several experiments with bird eggs showed a high mortality of embryos exposed to EMR from mobile phones [36,106,107]. EMFs increases mortality of tadpoles [98]. The EMR alters the immune, nervous, and endocrine systems, and operates independent or together with other factors like UV-B radiation or chemical pollutants. Death of embryos in nature is not due to UV radiation as the capacity of DNA repair mechanisms like photolyase (photoreactivating enzyme) is effective [9]. EMR produces stress on the immune system [76,98] that obstructs DNA repair [42,108,109]. Heat shock proteins may play a role in protecting amphibians from UV-B damage [14] and animals exposed to EMR [27,51,71,110,111]. Different susceptibility to UV among species and even among populations exists [112], as seen with EMR [31,40].

Hallberg and Johansson [108,109] proposed that radiofrequencies increase the effects of UV radiation. A study on the causes of melanoma in humans conclude that the incidence increases and the mortality associated with this skin tumor cannot only be explained by the elevation in UV sun radiation, but rather by the continuous alterations on mechanisms of cellular repair, produced by EMR (radiofrequencies) resonant with the body, that amplify the carcinogenic effects of the cellular damage induced by the UV-B radiation. The cases of melanoma experienced a significant increase from the 1960–70s [108] that continues today, and also asthma and several types of cancer associated with deterioration of immune system. Data suggest there is an increase of electromagnetic pollution [108,113]. The public health situation in Sweden has become worse since the autumn of 1997. There is a correlation between the massive roll-out of GSM mobile phone antennae and adverse health effects [109].

Enigmatic decline of amphibian species are positively associated with streams at high elevations in the tropics and negatively associated with still water and low elevations [3]. In high places, the electromagnetic contamination is usually higher [47]. Microwave measurements of power density as low as $0.0006\,\mu W\,cm^{-2}$ show strong correlation with symptoms like depressive tendency, fatigue, and insomnia in humans [63].

Proposed research

To demonstrate the conclusive effect of microwave radiation on amphibians 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 [98]. Studies that try to correlate populational evolution, appearance of deformities, or the presence or absence of amphibians with measurements of electromagnetic fields from radiofrequencies will be of great interest. Field investigations of urban park populations and phone masts surrounding territories need to be high-priority. A radius of $1\,km^2$ laid out in concentric circumferences at intermediate distances may be useful to investigate the differential results among areas, depending on their vicinity and corresponding levels of EMR. Laboratory studies on amphibians exposed to pulsated and modulated microwaves would also be of great interest.

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EXHIBIT CR 20

Briefing Paper on the Need for Research into the Cumulative Impacts of Communication Towers on Migratory Birds and Other Wildlife in the United States
Division of Migratory Bird Management (DMBM), U.S. Fish & Wildlife Service – for Public Release

LAST UPDATED: April 17, 2009 [Comm Tower Research Needs Public Briefing-2-409.doc]

ISSUE: The number of communication towers including radio, television, cellular, microwave, emergency broadcast, national defense, and paging towers has grown exponentially in the U.S. over the past decade. These towers present health and safety challenges for humans, but they are also a growing impact to populations of migratory birds, 4-5 million of which are conservatively estimated to die each year in tower and guy-wire collisions (Manville 2005, 2009). Virtually unknown, however, are the potential effects of non-ionizing, non-thermal tower radiation on avifauna, including at extremely low radiation levels, far below maximum safe[1] exposure levels previously determined for humans.

This briefing paper addresses the need to cumulatively assess the impacts of communication towers on migratory birds both from collisions and radiation, especially neotropical migratory songbirds that are most impacted (Shire *et al.* 2000). The paper discusses some suggested research protocols needed to conduct a nationwide cumulative impacts analysis that would assess effects of tower collisions and radiation on avifauna and on other wildlife pollinators including bats and bees.

BACKGROUND

Light Attraction to Birds in Inclement Weather

Beginning with the earliest reported bird-tower kill in the U.S. (in September 1948 at a 137-m [450-ft] radio tower in Baltimore, MD [Aronoff 1949]), the nighttime attraction of lighting during inclement weather has proved to be a key liability for birds. However, much of the past research focused on carcass collections that were not necessarily correlated to nighttime lighting or to weather events. For example, the first long-term study of the impact of a television tower on birds began in 1955 by the Tall Timbers Research Station in FL. After the first 25 years of the study, 42,384 birds representing 189 species were tallied (Crawford and Engstrom 2001). Kemper (1996) reported collecting more than 12,000 birds killed in inclement weather on one night at a television tower in Eau Clair, WI. Manville (2005, 2007) provided additional details of documented bird-tower collision studies in the U.S., especially in regard to lighting and weather events.

Recently, Gehring *et al.* (2006, 2009) reported where red, steady-burning lights were extinguished allowing only flashing or strobe lights to persist on towers, the lighting change-out resulted in up to a 71% reduction in avian collision mortality at towers in MI. In a short-term

[1] "Safe" levels were based on thermal heating standards, now inapplicable. The standards are nearly 25 years out of date, and the EPA office tasked to direct the human safety issues was eliminated due to budget cuts in the early 1980s. Furthermore, the standards in place do not address the potential effects of radiation on wildlife. No government agency currently monitors the rising background levels of electromagnetic radiation (EMF). Current safety standards assume that non-ionizing radiation is safe if the power is too weak to heat living tissue. However, since the 1980s, growing amounts of published research are showing adverse effects on both humans and wildlife far below a thermal threshold – usually referred to as "non-thermal effects," especially under conditions of long-term, low-level exposure (DiCarlo *et al.* 2002, Levitt and Morrow 2007).

study, Evans *et al.* (2007) looked at lighting attraction at ground level in complete cloud cover, but found that neither red, steady-burning nor red flashing lights induced bird aggregation. They hypothesized that the disorientation to red light only occurs if birds are actively using magnetoreception and the red light creates an imbalance in the magnetoreception mechanism. Additional studies are underway to better understand the mechanisms of lighting attraction.

Published research protocols developed to count and estimate bird-tower kills have been developed (*e.g.*, Avery *et al.* 1978, Manville 2002, Derby *et al.* 2002, and Gehring *et al.* 2009) and will be briefly reviewed below for use in future cumulative effects assessments for both collision and radiation studies.

<u>Potential Radiation Impacts to Birds</u>

In 2002, T. Litovitz (Catholic University, pers. comm.; DiCarlo *et al.* 2002) raised troubling concerns about the impacts of low-level, non-thermal radiation from the standard 915 MHz cell phone frequency on domestic chicken embryos under laboratory conditions. Litovitz noted deformities, including some deaths of the embryos subjected to hypoxic conditions under extremely low radiation doses[2].

Preliminary research on wild birds at cellular phone tower sites in Valladolid, Spain, showed strong negative correlations between levels of tower-emitted microwave radiation and bird breeding, nesting, and roosting in the vicinity of the electromagnetic fields (Balmori 2003). Birds had historically been documented to roost and nest in these areas. House Sparrows, White Storks, Rock Doves, Magpies, Collared Doves, and other species exhibited nest and site abandonment, plumage deterioration, locomotion problems, and even death among some birds found close to cellular phone antennas. Balmori did not observe these symptoms prior to construction of the cell phone towers. Balmori (2004, 2005) noted that the White Stork appeared most heavily impacted by the tower radiation during the 2002-2004 nesting season in Spain. Manville (2005) reported Balmori's (2003) preliminary results, and raised concerns of similar events in the U.S.

Everaert and Bauwens (2007) found strong negative correlations between the amount of radiation presence (both in the 900 and 1800 MHz frequency bands) and the presence of male House Sparrows. In areas with high electric field strength values, fewer House Sparrow males were observed. Everaert and Bauwens' preliminary conclusion, long-term exposure to higher radiation levels was affecting bird abundance or bird behavior in this species. Balmori and Hallberg (2007) reported similar declines in House Sparrows directly correlated with levels of electromagnetic radiation in Valladolid, Spain.

Of concern to DMBM are the potential impacts of radiation on bird populations. Beason and Semm (2002) tested neural responses of Zebra Finches to 900 MHz radiation under laboratory conditions and showed that 76% of the neurons responded by 3.5-times more firings. No studies have yet been conducted in the U.S. on radiation impacts to wild bird populations. Magnetite, a mineral highly sensitive to electromagnetic frequencies (EMFs), has been discovered in human, bird, and fish brains. It has been suggested that radio frequency radiation (RF) may be acting as an attractant to birds since their eye, beak and brain tissues are loaded with magnetite, a mineral highly sensitive to magnetic fields that birds use for navigation (Ritz *et al.* 2004, R. Beason cited in Levitt and Morrow 2007). Communication tower radiation in the U.S. may already be impacting breeding and migrating populations of birds, bees, and other wildlife, based on research conducted in Europe. It is therefore important to gain a far better understanding of the

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[2] *i.e.*, doses as low as 1/10,000 below the allowable "safe" level of radiation (T. Litovitz 2002 pers comm.; DiCarlo *et al.* 2002).

suspected impacts of radiation on birds and other wildlife, particularly if those suspected impacts are having effects on species at the population level.

Potential Radiation Effects on Other Pollinators

Radiation has also been implicated in effects on domestic honeybees, pollinators whose numbers have recently been declining due to "colony collapse disorder" (CCD) by 60% at U.S. West Coast apiaries and 70% along the East Coast (Cane and Tepedino 2001). CCD is being documented in Greece, Italy, Germany, Portugal, Spain, and Switzerland. One theory regarding bee declines proposes that radiation from mobile phone antennas is interfering with bee navigational systems. Studies performed in Europe have documented navigational disorientation, lower honey production, and decreased bee survivorship (Harst *et al.* 2006, Kimmel *et al.* 2006, Bowling 2007). This research needs further replication and scientific review, including in North America. Because pollinators, including birds, bees, and bats, play a fundamental role in food security (33% of our fruits and vegetables would not exist without pollinators visiting flowers [Kevan and Phillips 2001]), as pollinator numbers decline, the price of groceries goes up.

Harst *et al.* (2006) performed a pilot study on honeybees testing the effects of non-thermal, high frequency electromagnetic radiation on beehive weight and flight return behavior. They found that of 28 unexposed bees released 800 m (2,616 ft) from each of 2 hives, 16 and 17 bees returned in 28 and 32 minutes, respectively, to hives. At the 1900 MHz continuously-exposed hives, 6 bees returned to 1 hive in 38 minutes while no bees returned to the other hive. In exposed hives, bees constructed 21% fewer cells in the hive frames after 9 days than those unexposed. Harst *et al.* selected honeybees for study since they are good bio-indicators of environmental health and possibly of "electrosmog." Because of some concerns raised regarding the methods used to conduct the Harst *et al.*(2006) study, specifically the placement of the antenna where bees could contact it (*i.e.*, potentially a bias), the experimental methods need to be redesigned and the studies retested to better elucidate and fine tune the impacts of radiation. The results, while preliminary however, are troubling. Kimmel *et al.* (2006) performed field experiments on honeybees under conditions nearly identical to the Harst *et al.* (2006) protocol except that bees were stunned with CO_2 and released simultaneously 500 m (1,635 ft) from the hives. However, in one of their experimental groups, they shielded the radiation source and antenna in a reed and clay box to address potential biases raised in the Harst *et al.* study. Sixteen total hives were tested, 8 of which were irradiated. After 45 minutes when the observations were terminated, 39.7% of the non-irradiated bees had returned to their hives while only 7.3% of the irradiated bees had.

RESEARCH DISCUSSION

If communication tower collisions are killing 4-5 million or more birds per year in the U.S. due to collisions, what impact – if any – might radiation have on avifauna? Bees? Other wildlife? We simply do not know. In 2000, the Communication Tower Working Group (chaired by DMBM/Manville) developed a nationwide tower research protocol that would assess cumulative impacts from tower collisions nationwide, suggesting the use of some 250 towers of different height, lighting, and support categories. The preliminary cost estimate for a 3-year study was $15 million. No funding was ever acquired and the collision study has not yet been conducted.

The proposed 2000 study was to focus on the collision impacts of communication towers to birds during spring and fall migrations, but the same types of mortality monitoring could be conducted during the late spring/summer breeding seasons, looking particularly for evidence of injury and death to breeding birds in close proximity to communication towers. Radiation levels would need to be measured at the tower sites and nests adjacent to the towers during nesting activity, and bird behavior would also need to be monitored throughout the breeding season. Laboratory necropsies would need to be performed on birds and other wildlife suspected of impacts from radiation to better understand what caused their deaths and to verify that they did not die from blunt force trauma from tower or wire collisions. Pre-construction studies should be performed to assess habitat use by breeding and resident avifauna. Post-construction studies should assess site abandonment, development of deformities, injuries, and deaths. A careful review of the protocols developed by Balmori (2004, 2005), Balmori and Hallberg (2007), Everaert and Bauwens (2007), and others is critical because similar studies should be performed in the U.S.

METHODS FOR ASSESSING AVIAN COLLISION MORTALITY

Methods for Assessing Tall Tower Mortality

Bird strike mortality studies at "tall"[3] communication towers conducted previous to research performed by Avery *et al.* (1978) indicated that most dead birds were found within 60 m (197 ft) of the central communication tower structure. Avery *et al.* assessed songbird mortality at a 369-m (1,210-ft) Omega Loran U.S. Coast Guard tower in ND. Based on daily monitoring during 3 fall and 2 spring migration seasons, 63% of the birds they found dead or injured at this tower were within 92 m (300 ft) of the tower. Avery *et al.* placed tagged bird carcasses (*e.g.*, House Sparrows and European Starlings) in catchment nets and on non-netted habitats (*e.g.*, gravel pads, roads, and marshy plots) to assess persistence and scavenging/predation loss. They completely examined the inner 46-m (150-ft) radius of the tower (concentric circle designated "A") for bird carcasses, including both the areas covered with catchment nets and the non-netted areas. Placing tagged carcasses in random search plots, which are then found or not found and/or removed or not removed, helps determine biases (Erickson *et al.* 1999). However, there are inherent problems associated with using tagged bird carcasses, including the attraction of predators, cost, availability, and adequate sample size (D. Strickland, WEST Inc., pers. comm.).

In addition to the total area assessed during this study (168 ha [415 ac]), for the remainder of the search area, Avery *et al.*(1978) divided the habitat into concentric circles of radii 92 m (designated "B"; 303 ft) , 183 m (C; 600 ft), and 731 m (D; 2,398 ft), respectively. Two compass lines (north-south and east-west) divided B, C, and D into 12 substrata beyond the inner core. In each of the substratum, 2 net catchment sampling plots, 12.4 m (41 ft) on a side, were randomly selected. Nylon netting suspended on steel frames 1.5 m (5 ft) high, with the net's center anchored to the ground, was utilized. See Manville (2002) beyond for additional net details.

Sampling nets were demonstrated by Avery *et al.*(1978) to be highly effective in preventing losses to scavengers and predators; none of 33 of the test birds placed in nets during the Avery *et al.* study were taken during the first night, but 12 of 69 test birds placed on non-netted gravel sampling plots were taken during the same period. During the Avery *et al.* study, dead bird searches were made daily at dawn during the peak of songbird migration. In a study at a Tallahassee, FL, television tower – where sampling nets were not used – scavenging was considerably higher; only 10 of 157 birds were left undisturbed after one night (*i.e.*, 93.6% scavenging; Crawford 1971).

Homan *et al.* (2001) placed carcasses of House Sparrows in dense vegetation, comparing searcher efficiencies of humans and canines. The dogs received no special training in carcass searching.

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3 hereafter, towers greater than 61 m (199 ft) above ground level (AGL), generally guyed, and always lit at night.

Thirty-six trials were conducted in 5 x 40–m (16 x 131-ft) study plots. Humans found 45% of the carcasses while dogs found 92%. The ratio of recovered to missed carcasses was approximately 12:1 for dogs and 1:1 for humans, making dogs much more efficient in finding carcasses. Searcher efficiencies were not improved but remained similar when testing residual cover (April searches) versus new growth cover (August searches). Because the protocol in the Homan *et al.* study improved quantitative and qualitative assessments, it provides considerable promise for the research initiatives being proposed in this briefing paper.

Arnett (2006) further tested the dog-search protocols of Homan *et al.* (2001) and others, assessing the abilities of dog-handler teams to recover dead bats at 2 commercial wind turbine facilities. Dogs found 71% of the bats placed during searcher-efficiency trials at Mountaineer, WV, and 81% of those at Meyersdale, PA, while human searchers found only 42% and 14% of the carcasses, respectively. Both dogs and humans found a high proportion of the trial bats within 10 m (33 ft) of the turbine tower, usually in open ground (88% and 75%, respectively). During a 6-day fatality search trial at 5 Mountaineer turbines, dog-handler teams found 45 carcasses while human searchers during the same period found only 19 (42%). As vegetation height and density increased, humans found fewer carcasses while dog-handler team searcher efficiencies remained high. Arnett's (2006) study further reinforces the hypothesis that use of dogs greatly improves efficiencies in finding dead bats very similar to what Homan *et al.* (2001) found for locating passerines. Dog use should be given serious consideration in conducting bird and bat mortality studies at telecommunications towers.

From 2003 through 2005, Gehring *et al.* (2006, 2009) studied 24 tall communication towers in MI. They used flagged, straight-line transects, each technician walking at a rate of 45-60 m (147-196 ft) per minute and searching for carcasses within 5 m (16 ft) on either side of each transect, as suggested by Erickson *et al.* (2003). The transects covered a circular area under each tower with a radius equal to 90% the height of the tower. The straight line transects were much easier to navigate than were circular transects (J. Gehring, Michigan Natural Features Inventory, pers. comm.). Due to dense vegetation, observer fatigue, human error, scavenging by predators, and crippling loss of birds and bats that may have escaped the detection area, Gehring *et al.* tested each technician's observer detection rate and rate of carcass removal. Ten bird carcasses of predominately Brown-headed Cowbirds, with painted plumage to simulate fall song bird migration plumage, were placed once each field season within each study plot to assess observer efficiencies. Likewise, 10-15 predominately Brown-headed Cowbirds were placed by each technician at the edge of designated tower search area to monitor the daily removal of carcasses by scavengers. These carcasses were not painted to avoid placing any foreign scent on them. No catchment nets were used in this study.

Methods for Assessing Short Tower Mortality

Manville (2002) developed a protocol for the U.S. Forest Service (USFS) to study the effects of cellular telecommunications towers on birds and bats, recommending use of elevated catchment nets for a Coconino, Kaibab, and Prescott National Forest study in AZ. Modifying the Avery *et al.* (1978) search protocol, Manville suggested use of 1.9-cm (0.75-in) mesh knitted polyethylene nets, 15 x 15 m (50 x 50 ft) in size, suspended 1.5 m (5 ft) above ground, with 8 gauge monofilament nylon line attached around the periphery of the entire net, supported with 2-m-long (6.5-ft) steel angle posts driven into the ground and spaced every 2-3 m (7-10 ft) apart. He recommended pulling the center of each net close to the ground, securing with monofilament to a cinder block, thus creating a downslope gradient from the edge of the net to its center so a carcass landing in the net would tend not to be blown from the netting edge to the ground by a strong wind. He did not recommend using a wooden lip on the net's edges as Avery *et al.* (1978) had suggested. Materials for each net were estimated to cost $320 (Avery and Beason 2000).

Manville (2002) postulated that use of elevated catchment nets would make finding dead birds killed by tower strikes more reliable, especially under variable habitat conditions (*e.g.*, unsuitable substrate for searching, tall grass, shrubs, roots, boulders, or trees). Manville recommended breaking down the tower's circumference into 3, 120° arcs, then breaking the study plot into 2 concentric circles. The radius of the first circle from the tower's center was 30 m (100 ft) and nets were to be randomly deployed to cover 24% of the total area of that concentric circle, 1 net randomly placed in each 120° arc. For the second concentric circle (30-60 m in radius from the center [100-197 ft]), nets were placed randomly in 8% of the total area, 1 net randomly placed in each of the 3 arcs.

Manville (2002) did not recommend using tagged bird carcasses in the AZ study because he believed that double sampling would address sampling efficiency biases. Double sampling involves (1) net sampling, allowing for an estimate of the number of carcasses that fall beneath each tower and are relatively unbiased for searcher efficiency and carcass removal, and (2) ground sampling where biases are inherent. For short towers, he recommended the entire area the radius of the tower height be completely searched (including under the nets) at dawn each day during the migration season and once weekly during the breeding season. Net sampling allows for adjustment of the ground sampling estimates that would correct for carcass removal and searcher efficiency bias based on the relative difference of the number of carcasses found using the 2 sampling methods at each communication tower studied.

Manville (2002) indicated that the probability of catching a bird in a net would change with increased distance from the tower (*i.e.*, birds my fly or be carried by the wind for a distance before dying). He suggested that if there is a bias because birds tend to die greater than 30 m (100 ft) from a short tower, probabilities can be determined by searching strip transects that radiate from a tower. He recommended using a transect 1.5- 2 times the height of the tower, 15 m (50 ft) wide, placed on a randomly selected compass line. Carcass searches within the transect should help to estimate the area that should be sampled by nets, develop a correction factor outside the radius of the area sampled by the nets, and improve the correction factor for ground surveys conducted exclusive of the net surveys. Manville suggested this transect survey be conducted at least once per week, preferably in the early morning hours, during both migration and breeding seasons. With the recent use of trained dogs to detect and locate dead and injured birds and bats, where dogs have been shown to be at least 50% more effective in finding carcasses, dog use should be considered a viable monitoring alternative (E. Arnett, Bat Conservation International, pers. comm., Homan *et al.* 2001, Arnett 2006).

Derby *et al.* (2002) modified the Manville (2002) protocol to conduct the cellular telecommunications tower study in AZ for the USFS. There, 6 of the 7 cell towers were surrounded by 3-m (10 ft) walls, 29 m (95-ft) long on each side. The walled square was divided into 4 equal blocks, and within 1 of these blocks a 12 x 12-m (40 x 40-ft) nylon mesh net was randomly placed based on net specifications recommended by Manville (2002) but placed > 3 m (10 ft) above the ground to allow company personnel to perform maintenance on the sites. Outside the walled compounds, Derby *et al.* used 4, 6 x 6-m (20 x 20-ft) nets, 3 of the nets randomly set outside the wall to a distance of 30.5 m (100 ft) from the tower, and the 4th net randomly placed in the band from 31 to 61 m (100-200 ft) from the tower. Inside the walled compound the entire area was searched by walking transects 6 m (20 ft) apart (3 m [10 ft] search width). The surveys were performed at dawn 4 times per week during peak songbird migration.

Derby *et al.* (2002) also recommended using straight line transects, 4 oriented perpendicular to the walls, and 4 diagonal from the corners of the wall – representing the "spokes of a wheel."

Each transect was 61 m (200 ft) long, and 6-m (20 ft) wide. Because the Derby *et al.* protocol also used double sampling, no tagged carcasses were used in their study.

Both Manville (2002) and Derby *et al.* (2002) recommended daily searches of all electrical wiring to assess for electrocution and wire collision mortality.

Homan *et al.* (2001) used Labrador retrievers and a Chesapeake Bay retriever to search 6 plots, 5 x 40 m (16 x 131 ft) in size, delineated by flagging, to detect 8 thawed House Sparrow carcasses randomly thrown in each of the plots from 1 m (3 ft) outside the plot, allowing the human or human-dog team to search each plot for 10 minutes. Dogs were kept on 5-m (16-ft) leashes during searches. Humans were active searchers when using the dogs. Searches were not conducted during steady rain or when winds were ≥ 32 km/hr (20 mph). The technique with leashed dogs could easily be used to survey both tall and short tower plots, based on the protocols previously recommended. With the dogs confined to leashes, additional training would be unnecessary.

Arnett (2006) used 2 trained chocolate Labrador retrievers to locate test bat carcasses of different species and in different stages of decomposition at commercial wind turbine facilities on the Appalachian Mountain front in PA and WV. His dogs were trained in basic obedience, "quartering" (*i.e.,* systematically searching back and forth in a 10-m-wide [33 ft] transect), and blind retrieval handling skills. The dogs were trained with dead bats 7 days prior to field trials. When a dog found a test bat, the dog was rewarded with a food treat if it performed the task of finding the bat, sitting or stopping movement when given a whistle command to do so, and leaving the carcass undisturbed. Arnett walked the transect lines at a rate similar to that of humans (*i.e.,* approximately 13-25 m/min [43-82 ft/min]) while the dogs were allowed to quarter the entire width of the transect (5 m [16 ft] on either side of the center line). While this technique was tested on bats, it also shows great promise for use on birds. Dogs would require additional training, but unlike the Homan *et al.* (2001) technique, they would not need to be leashed. The Arnette technique also shows great promise for use at both tall and short communication towers to locate dead birds and bats.

METHODS FOR ASSESSING RADIATION IMPACTS TO BIRDS

Methods for Assessing Radiation Impacts at Tall Towers

At present, radiation studies at tall towers in Europe have not yet been conducted since the impacts to birds and other wildlife have been documented at short, cellular communication towers. The methods suggested below for short tower radiation studies should also be applicable to future tall tower radiation studies.

Methods for Assessing Radiation Impacts at Short Towers

Balmori (2005) selected 60 nests of White Storks in Valladolid, Spain, to monitor breeding success, visiting each nest from May to June 2003, taking care to select nests with similar characteristics located on rooftops. Tree nests were not studied. Nests were selected based on very high (N=30) or very low (N=30) exposure levels of electromagnetic radiation, depending on the distances nests were located from the cell towers. Thirty nests were within 200 m (656 ft) of the towers, while the remaining 30 were located > 300 m (981 ft) beyond any tower. Chick productivity was closely observed. Electric field intensities (radiofrequencies and microwave radiation) were measured using a unidirectional antenna and portable broadband electric field meter set at 10% sensitivity. Between February 2003 and June 2004, 25 visits were made to nests located within 100 m (327 ft) of 1 or several cell phone towers to observe bird behavior. The visits were made during all phases of breeding, from nest construction until Stork fledging. RFs and EMFs were also measured at all nest sites using a unidirectional antenna and field meter.

Balmori and Hallberg (2007) studied the urban decline of House Sparrows in Valladolid, Spain, since this species is in significant decline in the United Kingdom and western Europe, and because it usually lives in urban environments, where electromagnetic contamination is higher. They felt it would be a good biological indicator for detecting the effects of radiation. Forty visits, approximately 1 per month were made between October 2002 and May 2006, and were performed at each of 30 point transect locations (*i.e.*, point counts, the protocol recommended by Bibby *et al.* 2000) between 7 a.m. and 10:00 a.m. by the same ornithologist following the same protocol. At each transect site, all sparrows heard and seen were counted, without differentiating birds by sex and age, and radio frequencies and levels of microwave radiation were recorded using a unidirectional antenna and a portable broadband electric field meter set at 10% sensitivity. Bird densities from each point were calculated based on the number of sparrows per hectare.

Everaert and Bauwens (2007) counted male House Sparrows during the breeding season at 150 point locations (Bibby *et al.* 2000) in 6 residential districts in Belgium, each point location situated at variable distances (mean= 352 m [1,151 ft]; range= 91- 903 m [298- 2,953 ft]) from nearby cell phone antenna towers. Point counts were conducted for 5 minutes, all male House Sparrows heard singing or visible within 30 m (98 ft) were counted, counts occurred between 7 a.m. and 11:00 a.m. when males were most active, and counts were conducted only during favorable weather conditions. Electric field strengths at 900 MHz and 1800 MHz were measured for 2 minutes at each frequency using a portable calibrated high-frequency spectrum analyzer with a calibrated EMC directional antenna. To measure maximum radiation values, the EMC antenna was rotated in all directions.

METHODS FOR ASSESSING RADIATION IMPACTS TO BEES

Methods for Assessing Radiation Impacts to Bees

Harst *et al.* (2006) exposed 4 beehives to 1900 MHz radiation from an antenna placed at the bottom of each hive immediately under the honeycombs, while they left 4 hives unexposed. Each of the 8 colonies contained approximately 8,000 bees. They were set up in a row, with a block of 4 hives equipped with DECT (Digital European Cordless Telecommunications) stations on the bottom of each hive. Metal lattices were installed between the exposed hives to avoid possible effects to the non-exposed control group. The average transmitting power per station was 10 mW, with peak power at 250 mW. The sending signal was frequency modulated and pulsed with a pulsing frequency of 100 Hz. A transparent 10 cm (4 in) plastic tube with a diameter of 4 cm (1.6 in) was mounted at the entrance of each hive to collect single bees and watch them return later to the hives. Twenty-five bees from each hive were randomly selected, stunned in a cooling box, marked with a marker dot on the thorax, and released 800 m (2,616 ft) away from the hives. All marked bees were released simultaneously and were timed from the moment of their release. Return times were noted as the bees each entered the plastic tubes, with the observation lasting 45 minutes. Any bees returning after 45 minutes were disregarded. Bees were able to touch the radiation sending antenna within the hive. Some have asserted that the antenna placement may have resulted in a behavioral bias in regard to bee response, raising a legitimate concern about the methods used to test bee response to radiation in this experiment.

Harst *et al.* (2006) also studied the effects of radiation on bee building behavior using the protocol discussed above. They photographically documented change in honeycomb area, and measured development of honeycomb weight for each hive. Sixteen colonies were selected for this experiment, 8 of which were irradiated, all aligned in a row. At the beginning of the experiment, the empty honeycomb frames were weighed, the hives were filled with bees (400 g [14 ounces]), and provided 250 ml (0.26 quart) food. Bees were fed 2 more times during the 9-day experiment. The honeycombs were photographed each day. The placement of the sending antenna, as previously suggested, may have altered bee behavior and hive productivity.

Kimmel *et al.* (2006) tested 16 bee colonies, 8 of which were irradiated. The experiment was nearly identical to that utilized by Harst *et al.* (2006) except that the sending antenna in 1 experimental group was shielded in a reed and clay box to address concerns about behavioral biases raised in the Harst *et al.* study. Bees were paralyzed using CO_2 instead of cold and were simultaneously released 500 m (1,635 ft) from the hives instead of 800 m (2,616 ft).

RESEARCH RECOMMENDATIONS FOR ASSESSING AVIAN COLLISION IMPACTS

Tall Tower Collision Research Recommendations

We recommend using either the Avery *et al.* (1978) or the Gehring *et al.* (2006, 2009) protocol for tall tower collision studies, depending on the feasibility and availability of catchment nets and dead bird carcasses. Avery *et al.* provided the opportunity to use catchment nets, testing searcher efficiency and carcass removal by placing test carcasses on site (in nets and on the ground). The protocol presumes that the majority of carcasses will be found within a certain distance of the tower's base. The protocol has particular utility for studying very tall towers, especially where terrain around the structures is highly variable and difficult to traverse. It can be used as a standing protocol, or modified as a hybrid based on combining other techniques suggested within this paper such as the use of dogs (Homan *et al.* 2001, Arnett 2006). Dogs have tremendous promise for both tall and short tower studies. If trained hunting dogs are used, then the Arnett (2006) protocol is an excellent tool since the dogs can be used off-leash. However, if untrained hunting dogs are available, then the Homan *et al.* (2001) protocol using leashed dogs is an excellent option.

Gehring *et al.* (2006, 2009) also successfully assessed mortality at tall towers, but catchment nets were not deployed in this study. Due in part to timing, budget constraints, and number of towers studied, this protocol has significant utility where many towers need to be studied. It could also be modified by using trained dogs or incorporating catchment nets.

The statistical designs for both short and tall tower studies – both for assessing collisions and radiation impacts, should be worked out with qualified biometricians. Both the USFWS and the USGS/Biological Resources Discipline (BRD) have well qualified statistical expertise. They should be consulted early in the development of a proposed study.

In both short and tall tower studies, data collection must include all of the following: time of day each tower is examined, time spent searching each site, time since the last search, and weather conditions, particularly inclement weather. Weather data should include the previous night's temperature, wind, cloud cover (clear if $< 10\%$ cover, partly cloudy 10-90% cover, or overcast $>$ 90% cover), barometric pressure, rainfall, fog, obscuration, and other relevant weather conditions (Derby *et al.* 2002).

When bird and bat carcasses, and injured vertebrates are found, regardless of the sampling method, data must include tower identification number, name of species (if known), date of collection, closest transect, distance from the tower, azimuth to the tower, exact mapped location (GPS coordinates are very helpful), estimated number of days since death/injury, body condition, probable cause of death, and evidence of scavenging. The carcass is to be collected, numbered, and saved to be used in other investigations (Gehring *et al.* 2009) for which a Federal and possibly state salvage permit will be required (Manville 2002).

Short Tower Collision Research Recommendations

Depending on the availability and utility of catchment nets and the layout of the tower site, we recommend using either the Manville (2002), the Derby *et al.* (2002), Homan *et al.* (2001), or the Arnett (2006) protocols – the latter 2 with greatly improved searcher efficiency, or a hybrid of these methodologies. Manville (2002) suggested using elevated catchment nets, but due to double sampling, he did not recommend using tagged bird carcasses. He also recommended using random transects to adjust for biases.

Derby *et al.* (2002) modified the Manville (2002) protocol, specifically in regard to challenges created by the tower study site in AZ. A randomly-placed catchment net was used within the walled enclosure of each of the sites, and the entire area within the walled compound (ground and net) was searched. Four randomly placed catchment nets were also utilized beyond the walls. Due to double sampling, no tagged bird carcasses were utilized. The protocol could be used as a free-standing technique but should be searched daily during the entire peak of bird migration.

RESEARCH RECOMMENDATIONS FOR ASSESSING RADIATION IMPACTS TO BIRDS

Tall Tower Radiation Research Recommendations

For both short and tall tower studies, any nests close to a tower should be noted, with its GPS coordinates recorded. Breeding, nest success, and survivorship should be monitored, where possible. How birds use their habitats for breeding and residence should be noted, including any issues of site abandonment, egg and clutch failure, development of deformities, injuries, and deaths.

For both short and tall tower studies, where birds appear to be injured or killed by radiation, proximity of the bird/carcass to known nest or roost sites and towers should be noted. Radiation levels at the tower, carcass site, and the nest site should be recorded. Any abnormal behaviors should also be described. Laboratory necropsies should be performed on birds and other wildlife suspected of impacts from radiation to better understand what caused their deaths and to verify that they did not die from blunt force trauma due to collisions. Tower and ambient radiation should be measured using equipment and techniques suggested by Harst *et al.* (2006) and Kimmel *et al.* (2006), or variations of equipment and methods available in the U.S. See the methods section of this paper for specifics.

Where carcass counts need to be assessed at specific tall towers, we suggest using the tall tower collision mortality protocols, discussed above in the methods section of this paper.

Short Tower Radiation Research Recommendations

Depending on the avian species being studied, we recommend using the Balmori (2005) protocol for assessing potential impacts to colonial nesting species such as herons and egrets. Where passerines are to be studied, we suggest the use of the Everaert and Bauwens (2007) and Balmori and Hallberg (2007) protocols for assessing potential impacts. Refer to the methods section above for specific details.

Where carcass counts need to be made at specific short towers, we recommend using the short tower collision mortality protocols, discussed above in the methods section.

RESEARCH RECOMMENDATIONS FOR ASSESSING RADIATION IMPACTS TO BEES

Bees and other pollinators also deserve close scrutiny from the potential impacts of radiation, and their study should be included as part of the overall research effort suggested in this paper. In addition to testing and validating the protocol and results from the Kimmel *et al.* (2006) study (see background and methods sections above), which we recommend be performed at multiple locations in the U.S., bee behavior, hive productivity, and bee survivorship need to be field-tested at both tall and short towers in the U.S. Variations on the protocols used by Harst *et al.* (2006) and Kimmel *et al.* (2006) could easily be developed to field-test potential radiation impacts on bee navigation, flight behaviors, hive productivity, and bee survivorship around both short and tall towers. However, any research protocol developed to assess potential insect impacts – and for that matter, impacts to birds, bats, and other wildlife, must attempt to eliminate extraneous variables that may bias study results. These include everything from antenna placement in the Harst *et al.* (2006) study, to the impacts of diseases, parasites, weather and climatic events, pesticides, contaminants, and other mortality factors on insects and other wildlife. Fine-turning a research protocol must include the combined efforts of trained entomologists, research radiation specialists, ornithologists, wildlife biologists, and biometricians.

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Towers, Turbines, Power Lines, and Buildings – Steps Being Taken by the U.S. Fish and Wildlife Service to Avoid or Minimize Take of Migratory Birds at These Structures

Abridged title: ***Minimizing Take of Migratory Birds at Structures***

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Abstract. As imperiled bird populations continue to increase, new challenges arise from the effects of growing numbers of communication towers, power lines, commercial wind facilities, and buildings. This paper briefly reviews steps the USFWS is taking to seriously address structural impacts to migratory birds. New findings will be briefly reviewed that address lighting impacts, new challenges facing birds from tower radiation, and collision and habitat fragmentation effects on avifauna. See the paper in this volume by Klem on his ongoing research with building glass, lighting and windows for details in trying to resolve those challenges.

Second-language title

Second-language abstract.

INTRODUCTION

This paper focuses on research initiatives, scientific breakthroughs, promising applications, policy efforts, and voluntary guidance discussed since the 3rd International Partners in Flight Conference held in Asilomar, CA (Manville 2005). Since the release of bird status reports at the Asilomar Conference, bird populations have continued to slump, and the list of North American birds with declining populations or otherwise at risk at the regional and continental levels has increased since 2002 where 131 species were then designated (USFWS 2002). Today, these include 147 species on the 2008 Birds of Conservation Concern list (USFWS 2008), 92 birds Federally listed as Threatened or Endangered on the Endangered Species Act (ESA), State-listed species, and species listed as high priorities on the U.S. Shorebird Conservation Plan, among others. The growing documented and suspected impacts of structures on birds – from direct collision mortality, electrocutions, cumulative effects, and from habitat fragmentation, disturbance and site avoidance – bode poorly for our avifauna.

Migratory birds – of which there are currently 836 designated species – are a Federal trust resource managed and protected by the U.S. Fish and Wildlife Service (USFWS or Service). The published list of the 836 species is found at 50 CFR Ch. 1, 10.13, List of Migratory Birds. As an agency, our regulatory goal is to "avoid or minimize unpermitted take" – i.e., impacts – essentially to ensure that we do no harm to these species. Unfortunately, with the growing current challenges, we have not done a very good job reaching that goal.

From what we know or suspect about impacts from structures, the combined effects of direct annual mortality from communication towers, wind turbines, power lines and buildings (both single story and tall structures) may for some species be causing impacts at the population level. This is very troubling. However, the estimates of structurally-caused mortality are at best, "guesstimates" of what actually may be happening in the wild, usually based on extrapolations from individual studies or small-scale surveys. Very few communication towers, commercial wind turbines, power transmission and distribution lines, and buildings are being studied on a full-season, let alone a year-round, basis, in a robust and scientifically rigorous manner, and in any level of detail that would help us better understand cumulative impacts caused by these structures.

Tens of millions of kilometers of power distribution lines are probably present in the U.S. today, but we lack any concrete accounting for their lengths (Williams 2000). However, data from the Electric Power Research Institute (EPRI) on the power transmission line lengths in the U.S. indicate the presence of at least 862 207 km (535 865 mi) of line (J.W. Goodrich-Mahoney, Senior Project Manager, Environment, EPRI, 2008 pers. comm.) – both transmission and distribution lengths growing as demands for power increase. Transmission lines are characterized as those carrying ≥ 69kV of electricity.

Unfortunately, very few communication towers and few kilometers of distribution and transmission lines are ever searched for dead or injured birds primarily due to lack of personnel, funding, and a perceived lack of importance. Virtually no systematic mortality studies are presently being conducted at buildings. Exceptions include 1) migration seasonal surveys being conducted by the staff of the Fatal Light Awareness Program in Toronto, Ontario, Canada (M. Mesure, Director, FLAP, 2007 pers. comm.), 2) efforts by staff and volunteers of the New York City Audubon Society (R. Creshkoff, volunteer, NYCA, 2007 pers. comm.), and 3) research being conducted by D. Klem (2008 pers. comm.) at Muhlenberg College, Allentown, PA. Although mortality studies are increasing at commercial wind turbine facilities, no full-season studies have yet been conducted in the East, and little research made available to the public is being conducted at Texas wind facilities – the State currently leading the nation in installed wind capacity (e.g, 7116 megawatts [MW]; AWEA 2009).

Direct mortality from collisions and electrocutions is, however, only part of the overall impact. The effects and impacts from fragmentation, site avoidance and disturbance – be they from communication towers, wind turbines, power lines, or commercial and residential buildings – are often difficult to quantify and are only now beginning to be understood. For example, the footprint from a hypothetical 600-turbine, 1200 MW (i.e., 2-MW per turbine) industrial wind project, the power grid and related infrastructure servicing it, and the road system connecting it, can hugely impact the habitat, especially for species sensitive to development such as "prairie grouse" and sage-steppe-obligate songbirds. Species such as the Federally endangered Whooping Crane (*Grus americana*) can also be put at direct risk from turbines, power lines and communication towers, both at their overwintering grounds and during migration. With 2008-2009 near-record winter Crane mortality from apparent starvation at n= 18 bird deaths, structural concerns raise further apprehension among biologists (T. Stehn, National Whooping Crane Coordinator, USFWS 2009 pers. comm.). With the current push to rapidly develop renewable energy, and as energy demands increase and as new power grids are constructed, more issues involving fragmentation, site avoidance, disturbance, and cumulative effects will result. While, with funding and staffing constraints, we may not see detailed cumulative analysis surveys conducted on tall structures during our lifetime, there is some good news. For all the aforementioned structures, some "corrective tools" and "conservation measures" are available to significantly reduce (in some cases, scientifically validated, while in others, based on anecdotal reviews) structural impacts on protected bird species. This paper focuses on some of these promising "tools."

COMMUNICATION TOWERS

While difficult to track the actual number of communication towers constructed nationwide, the evidence clearly shows a continuing exponential expansion of cellular telephone, emergency broadcast, national defense, microwave, paging, and related tower growth. Based on current evidence (Federal Communications Commission [FCC] 2006), more than 100 000 lighted communication towers > 61 m above ground level (> 199 ft AGL) are sited in the U.S. today. The website www.towerkill.com is an excellent source of information to compare tower growth in each of the 50 states. By clicking on each state, tower expansion based on FCC statistics from 1998 and 2004 (i.e., towers in the 61-91 m [200-299 ft], 92-153 m [300-499 ft], 153-244 m [500-799 ft], and 245+ m [800+ ft] ranges) can easily be compared (W. Evans 2008 pers. comm.).

The expansion of digital television towers (DTV) appears to be relatively small, even with the requirement to convert to DTV by June 2009 under mandates of the 1996 Telecommunications Act, as amended, perhaps diminishing its impact on birds to less than what had been anticipated. However, since some radio and television towers commonly reach 611 m AGL (2000 ft), they are situated in direct conflict especially with neotropical migratory songbirds, particularly during night migrations when weather conditions are deteriorating and visibility is poor to negligible. Because songbirds tend to migrate in massive, "broad fronts," birds will almost certainly be put at risk irrespective of the tower's location (Gauthreaux and Belser 2006). Add tower lights to the scenario, and the potential for significant conflict and mass mortality is great.

TOWER COLLISION MORTALITY

Direct impacts of communication towers to migratory birds come from two sources, collisions and possibly from radiation exposure. Collisions represent a primary source of mortality and have been well documented since the late 1940s in the U.S. (Aronoff 1949, Kemper 1996, Manville 2005 and 2007a). From a collision perspective alone, 4-5 million birds are conservatively estimated to die each year in tower and guy-wire collisions – with high-end estimates at 40-50 million birds (Manville 2005). These figures are admittedly "guesstimates," but still based on the best available scientific evidence. Like all structural mortality estimates, not until scientifically valid, cumulative impact analyses are conducted will we clearly understand the level of impact each structure is having on bird populations.

However, until impacts are better understood – including the likelihood of additive mortality effects to some populations – the Service will continue to address impacts using the precautionary approach (UNEP 2002). The precautionary approach – also known as the precautionary principle – has its origin in European law. However, the precautionary approach was refined, based on the development and application of international law in light of scientific uncertainty, at the 1992 Earth Summit in Rio de Janeiro, most notably through Rio Principle 15. It states that, "Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." Simply put, where sound scientific evidence is not yet available and where uncertainty remains a concern, the Service will proceed with caution. For example, the voluntary tower guidelines developed and released by the Service (USFWS 2000) to properly site, construct, operate, and decommission communication towers are fundamentally based on proceeding with caution where uncertainty and risk are prevalent. As new scientific findings are discovered (e.g., eliminating steady-burning red tower side lights that were shown to reduce avian tower collisions at some towers in Michigan by up to 71% – see beyond), recommendations such as these are passed on to the FCC for rulemaking and Service guidelines will be updated. Therefore, realizing that cumulative impact assessments may not be performed in the short term, due especially to budget constraints and staffing limitations, the Service will take whatever actions it can, working in concert with the FCC, the Federal Aviation Administration (FAA), the communication tower industry, researchers, and the conservation community.

Documented bird collisions continue to be a problem. While C. Kemper documented the record for a one-night avian-tower collision of more than 12 000 birds retrieved and identified in 1963 at a Wisconsin television tower (Kemper 1996), spikes in tower collision numbers have recently been noted. For example, in continuing studies conducted by A. Clark over 29 years at three television towers in Buffalo, NY (Morris et al. 2003), Clark noted a gradual decrease in the number of birds killed at the towers he studied – ranging from a high of 4787 in 1982 to a low of 6 in 1992. The authors hypothesized the decline in the rate of mortality was due to 4 possible factors: 1) an overall decrease in migratory bird populations, 2) change in weather and wind patterns, 3) increases in predation and scavenging around tower bases, and 4) changes in migration patterns.

However, during the fall 2005 migration season, Clark (2006 pers. comm.) documented the largest annual kill at his study towers since 1982. In 2005, he retrieved 1223 birds at the bases of those same three New York towers (878 whole carcasses and 345 "parts thereof" representing 55 species). This included more than 200 Golden-crowned (*Regulus satrapa*) and Ruby-crowned Kinglets (*R. calendula*).

Also during the fall 2005 migration season, additional troubling reports of large bird kills at both tall and short communication towers also surfaced, particularly kills that occurred during a week-long inclement weather event that coincided in the East with the songbird migration in October. W. Evans (2005 pers. comm.) estimated more than 500 songbirds killed in a three-night period in mid-October at a 336-m AGL (1100-ft) tall tower near West Monroe, NY. Evans also reported several intact, but decaying warbler carcasses including a Hooded Warbler (*Wilsonia citrina*) at a 61-m AGL (200-ft) cellular telephone tower near Alfred, NY. During the same weather event, Evans also reported 147 salvaged birds, mostly Blackpoll Warblers (*Dendroica striata*), at an unlit cellular telephone tower in northern PA that appeared to be less than 46 m (150 ft) AGL. In the case of two cellular telephone tower morality events, nearby solid/steady-burning bright light sources appeared to result in the bird congregations that led to the kills (Manville 2007a). Also during the fall 2005, on 7-8 September and again on 13-14 September, an estimated 400 birds were killed each night at the 336-m AGL (1100 ft) WMTV tower near Madison, WI. In the second kill, 172 carcasses of 23 species were retrieved, including 5 Golden-winged Warblers (*Vermivora chrysoptera*) – of particular concern to USFWS since these are birds of conservation concern.

To begin to better understand the dynamics and the relationships between tower lighting, height, guy-wire supports, location, and impacts to birds, Gehring et al. (2006, 2009) performed a peer-reviewed study on $n=24$ towers in various, mostly random locations throughout Michigan. Begun in the fall 2003 and completed in the fall 2005, this study was the first to compare bird collision rates at communication towers equipped with different types of FAA obstruction lighting. Due to variances allowed in 2005 by the FAA on $n=18$ towers, steady-burning, non-flashing lights were extinguished. These included on, 1) all white strobe-lit towers (these towers were unaffected since no red lights are required by FAA on them), 2) all red strobe-lit towers, and 3) all red blinking, incandescent-lit towers. Lighting regimes for the aforementioned towers were compared to 4) three guyed towers with a combination of red strobes at the top and mid levels, and steady-burning red lights at the three-quarters and one-third height levels. This lighting regime represents the current lighting system for many communication towers nationwide (Gehring et al. 2009).

Based on the 2005 data, results strongly suggest that by extinguishing the red, steady-burning L-810 lights, but leaving on the strobe or incandescent blinking lights, avian collision mortality can be reduced by as much as 50-71%. Not surprisingly, the most birds killed were found under the tallest, guyed towers, consistent with many other reported studies (Manville 2007a). Gehring et al. (2009) recommended the extinguishing of L-810 lights, provided that the lighting system continues to remain safe for aviators. The FAA will begin pilot conspicuity studies in Michigan during spring and fall 2009 to assess pilot visibility of the towers without steady-burning red lights. If deemed safe, they will likely revise their Obstruction Marking and Lighting Advisory Circular (FAA 2000), giving tower operators the option of extinguishing the steady-burning lights, saving electricity, and significantly reducing bird mortality. No statistical differences were found in avian mortality rates among towers lit only with the different types of flashing lights – i.e., white strobe vs. red strobe vs. red flashing incandescent lighting. The results suggest that the flashing of a light is more important in reducing avian collisions than is the color of the light.

At this writing, J. Gehring has completed the fall 2008 season of a 3-year study of n=6 tall towers (> 277 m AGL [> 906 ft]) in Michigan, a 107 m AGL (350 ft) U.S. Coast Guard (USCG) Rescue 21 unguyed tower in Cape May, NJ, and will begin the study of a 138 m (450 ft) USCG Rescue 21 tower that is being built in the vicinity of Cape Hatteras, NC, where bird deterrent devices will be tested on guy support wires. Preliminary results suggest that, similar to the Michigan study of towers 116-146 m AGL, avian fatalities can be significantly reduced at taller communication towers by using only flashing lighting systems. Like the larger Michigan study (Gehring et al. 2009), preliminary data suggest that the unguyed tower in Cape May, NJ, is not involved in large numbers of avian fatalities. Further data collection and analysis are ongoing. The purpose of this study, in part, is to replicate the study in Michigan (Gehring et al. 2009), and if the FAA is willing to allow temporary light change-outs on several of these tall towers, we can test the effects of those changes on bird attraction and mortality.

Evans et al. (2007) subjected night-migrating birds in 100% cloud-cover conditions at ground level to alternating short periods of different artificial light, including various intensities, wavelengths, and flash rates from a ground-based lighting device. This study in October 2005 in Ithaca, NY, represented the first direct investigation of these variables causing bird aggregation in inclement weather. An acoustic transducer and directional microphone, positioned 5 m (16 ft) from the light source, were used to identify a strong or weak presence of birds near the light source.

Evans et al. (2007) performed spectrographic analysis on loud calls, basing species identification on the flight call reference guide produced by Evans and O'Brien (2002), and they visually documented bird presence on site. Birds were induced to congregate at all wattage levels of white steady-burning light tested. However, no aggregation was noted at the 1500 W white flashing halogen lights. The study results further reinforce conclusions reached by Gehring et al. (2006, 2009), Gauthreaux and Belser (2006), and J. Johnson (2005 pers. comm.).

However, Evans et al. (2007) did not find either steady-burning red (L-810) or red flashing (L-864) beacons induced bird aggregation when tested separately at ground level in 100% cloud cover. As one possible explanation, they suggested that the disorientation to red light only occurs if birds are actively using magnetoreception and the red light creates an imbalance in the magnetoreception mechanism. On clear nights, for example, some avifauna use star and moon light as sources for navigation, especially stellar arrays around the North Star (Sauer 1957, Emlen 1967). On cloudy nights, however, evidence suggests that birds may orient by sensing the axial inclination of the earth's magnetic field through a light-dependent mechanism, probably located in the avian eye (Wiltschko et al. 1993, Ritz et al. 2004, Thalau et al. 2005, Wiltschko et al. 2005).

Gauthreaux and Belser (2006) first published this hypothesis that aggregation around communication towers with red lights may be due to disruption of magnetoreception caused by the red light. W. Evans (2008 pers. comm.) has acknowledged the need for further study into bird aggregation, red light disorientation, cloud cover, and magnetoreception, and he hopes to replicate and expand the study to better understand the role of magnetoreception and bird aggregation. Efforts to conduct additional research are presently underway.

Just prior to the apparent "spikes" in tower mortality documented during the fall 2005 as summarized above, evidence was presented at the Research Subcommittee of the Communication Tower Working Group (CTWG) that continued to show increased impacts of lighting, tower height, and guy wire impediments to migratory birds, especially when night migration and inclement weather coincided.

In November 2006, the FCC published a Notice of Proposed Rulemaking (NPRM; FCC 2006) requesting suggestions and recommendations from the public and the agencies on how to address the effects of communication towers on migratory birds. Through the Service's Deputy Director, this author submitted detailed Service comments in February 2007 suggesting the following rulemaking changes. 1) Based on the study results from Gehring et al. (2006), the Service recommended removal of steady-burning L-810 lights where retrofits were being conducted, and the elimination of steady burning lights on all new tower construction where lighting is required (i.e., towers > 61 m [199 ft]), within 6.1 km [3.8 statute mi] of airport approach and departure controlled runways, and along interstate highways). 2) Based on a preponderance of information about impacts from tall, guyed towers, the Service suggested a "gold standard" for towers. Keep them unguyed, unlit, and < 61 m AGL (200 ft) wherever possible – ideally collocating new towers on existing structures. And 3), we recommended that migratory birds should become part of the FCC's National Environmental Policy Act (NEPA) review process for tower licensing. The rulemaking document and the comments provided above (Manville 2007a) are available in their entirety on the FCC's website under WT Docket 03-187, FCC 06-164, "Effects of Communication Towers on Migratory Birds" (most easily accessed by searching under FCC Docket 03-187, Effects of Communication Towers on Migratory Birds [Service comments included in docket file 2301-2400]).

A lawsuit was won on appeal by the American Bird Conservancy et al. against the FCC in the Court of Appeals for the District of Columbia in February 2008. ABC Inc. v.

FCC, 516 F.3d 1027 (2008) requires the FCC to evaluate the effects of communication towers on migratory birds in the Gulf Coast region, including through MBTA, NEPA, and ESA. While at this point the FCC has not yet finalized any rulemaking, currently responding to obligations set by the Court, it is hoped that the recommendations made above will be implemented very shortly. Each migration season delay means more needless bird deaths.

POSSIBLE TOWER RADIATION ISSUES

The radiation issue has only become a recent development with field studies begun around 2000 in Europe (Balmori 2003, 2005, Balmori and Hallberg 2007, Everaert and Bauwens 2007) and laboratory studies conducted in the U.S. during the late 1990s (T. Litovitz 2002 pers. comm., DiCarlo et al. 2002). Virtually unknown, however, are the potential effects of non-ionizing, non-thermal tower radiation on avifauna, including at extremely low radiation levels, far below the safe exposure level previously determined for humans. These "safe" levels were based on thermal heating standards, now inapplicable. The standards are now more than 25 years out of date, and the U.S. Environmental Protection Agency (EPA) office tasked to direct human safety issues was eliminated due to budget cuts in the early 1980s. No government agency currently monitors the rising background levels of electromagnetic radiation (EMF). Current safety standards assume that non-ionizing radiation is safe if the power is too weak to heat living tissue. However, since the 1980s, growing amounts of published research are showing adverse effects far below a thermal threshold – usually referred to as "non-thermal effects," especially under conditions of long-term, low-level exposure (DiCarlo et al. 2002, Levitt and Morrow 2007).

In 2002 in the U.S., T. Litovitz (2002 pers. comm., DeCarlo et al. 2002) raised troubling concerns about the impacts of low-level, non-thermal radiation from the standard 915 MHz cell phone frequency on domestic chicken embroyos (*Gallus domesticus*) under laboratory conditions (DeCarlo et al. 2002). Litovitz noted deformities, including some deaths of the embryos subjected to hypoxic conditions under extremely low radiation doses. These included doses as low as 1/10 000 below the allowable EPA "safe" level of radiation. Meanwhile, preliminary research on wild birds at cellular telephone tower sites in Valladolid, Spain, showed strong negative correlations between levels of tower-emitted microwave radiation and bird breeding, nesting, and roosting in the vicinity of the electromagnetic fields (Balmori 2003). Birds had historically been documented to roost and nest in these areas. House Sparrows (*Passer domesticus*), White Storks (*Ciconia ciconia*), Rock Doves (*Columba livia*), Magpies (*Pica pica*), Collared Doves (*Streptopelia decaocto*), and other species exhibited nest and site abandonment, plumage deterioration, locomotion problems, and even death among some birds found close to cellular phone antennas. Balmori did not observe these symptoms prior to construction of the cell phone towers. Balmori (2005) noted that the White Stork appeared most heavily impacted by the tower radiation during the 2002-2004 nesting season in Spain. Manville (2005) reported Balmori's (2003) preliminary results, and raised concerns of possible similar events in the U.S.

In continuing European studies, Everaert and Bauwens (2007) found strong negative correlations between the amount of radiation presence – both in the 900 and 1800 MHz frequency bands – and the presence of male House Sparrows. In areas with high electric field strength values, fewer House Sparrow males were observed. Everaert and Bauwens preliminarily concluded that long-term exposure to higher radiation levels was affecting bird abundance or bird behavior in this species. Balmori and Hallberg (2007) reported similar declines in House Sparrows directly correlated with levels of EMF in Valladolid, Spain.

Manville (2007b) raised this concern on behalf of the USFWS at an invited Congressional staff briefing. Although Beason and Semm (2002) tested the natural responses of Zebra Finches (*Taeniopygia guttata*) to 900 MHz radiation under laboratory conditions and showed that 76% of the neurons responded by 3.5-times more firings, no studies have yet been conducted in the U.S. on potential radiation impacts to wild bird populations. Magnetite, a mineral highly sensitive to EMFs has been discovered in human, bird, and fish brains. It has been suggested that the radio frequency radiation (RF) may be acting as an attractant to birds since their eye, beak and brain tissues are loaded with magnetite, a mineral highly sensitive to magnetic fields that birds use for navigation (Ritz et al. 2004, R. Beason cited in Levitt and Morrow 2007).

Based on research conducted in Europe, communication tower radiation may already be impacting breeding and migrating bird populations, as well as other wildlife. Manville (2007b) has thus suggested the need to replicate research conducted in Europe on apparent radiation impacts to birds from short, cellular telephone towers, replicating and perhaps modifying studies performed by Balmori (2005), Balmori and Hallberg (2007) and Everaert and Bauwens (2007) – attempting to tease out and better understand the dynamics of what may be taking place. Unfortunately, funding for such studies is as yet unavailable and the priority of such wildlife research remains low compared to other anthropocentric impacts.

COMMERCIAL WIND TURBINES

Commercial wind development in the U.S. continues to grow at an exponential rate. In 2007, the industry noted a > 45% growth in turbine development (AWEA 2008), and in 2008, records were further broken with 50% growth (AWEA 2009) Operating turbines are referred to as "installed capacity," generally measured in MW rather than in turbine numbers or turbine height and rotor swept area. By late 2008, the U.S. had > 25 170 MW of installed capacity, lead by TX, IO, CA, MN, and WA in decreasing order of capacity (AWEA 2009). With slightly more than 22 000 turbines installed and operating on the landscape today, and more than 155 000 turbines projected to be operating by 2020 (AWEA 2008, M. Tuttle 2007 pers. comm., National Renewable Energy Laboratory 2007 estimate), the Service has serious concerns about current and potential impacts which continue to grow exponentially. From a wildlife perspective, however, there is some good news. With the exception of the continued high collision mortality of raptors, such as Golden Eagles (*Aquila chrysaetos*), Red-tailed Hawks (*Buteo jamaicensis*) and others – including passerines – at Altamont Pass Wind Resource

Area, CA, and the death of *Birds of Conservation Concern* and Breeding Bird Survey declining species elsewhere, avian mortality is not particularly high, at least at the present time. While the wind industry currently estimates that turbines kill 58 000 birds per year in the U.S. (National Wind Coordinating Collaborative Wildlife Workgroup 2009 statistic), the Service estimates annual mortality at 440 000 birds (Manville 2005). This is based, in part, on inconsistencies in the duration and intensity of searches resulting in biases between search areas, the size of the search areas, failure to estimate mortality during peak periods of migration, impacts from wind wake turbulence and blade tip vortices, and biases from unaccounted crippling losses (after Huso 2008). Until a robust, scientifically rigorous cumulative impacts analysis is performed, we will not know with a high degree of certainly the true level of mortality. Admittedly, it still is relatively small. However, with high risk, wildlife-unfriendly sites being selected by wind proponents next to, for example, nesting Golden and Bald Eagles (*Haliaeetus leucocephlus*), and turbines placed on ridge lines where Golden Eagles and Peregrine Falcons (*Falco peregrinus*) migrate, Service concerns are elevated. Bats, unfortunately, represent a completely different situation based on the high documented take of bats in WV, PA, NY, OK, western Alberta, and elsewhere, and the apparent attraction of some tree roosting bats to tall structures including turbines (P. Cryan, USGS bat specialist, 2009 pers. comm.). Add to this the impacts from white-nosed syndrome, a likely fungal disease hugely impacting hibernating bats in the East and Northeast, and turbine mortality could become additive (P. Cryan 2009 pers. comm.). However, mortality represents only one of three concerns regarding wind development – and all other anthropocentric impacts, for that matter. Indirect impacts from fragmentation, disturbance and site avoidance are also a huge concern for wildlife. With the exponential growth of industrial wind development, the issue has also become one of cumulative impacts and additive mortality.

To begin addressing risk, the Service developed a Potential Impact Index (PII) to rank and score potential wind development sites in 2002. However, the PII lacked a component for assessing temporal and spatial use of airspace. To correct this shortcoming, DMBM submitted a research proposal for a Rapid Assessment Methodology (RAM) to the Service's Science Support Program (SSP) for funding in 2008. Approved as one of the three SSP proposals to be funded and implemented in 2009, the Service will work with USGS scientist D. Johnson at the Northern Prairie Wildlife Research Center to develop, field-test, validate, and perform workshops in using this tool. The RAM is intended to be a first-cut analysis of a site's suitability, ultimately allowing a potential wind development site to be ranked and scored based on its known or perceived level of risk to wildlife and their habitats. More information on the RAM can be found at www.nationalwind.org, then clicking on the presentations given at the Research VII meeting, October 29, 2008, Milwaukee, WI.

By asking the operative question, which "straw" (*i.e.,* impact) will eventually break the "camel's back," will wind energy become that anthropocentric source, will it be something else that impacts a population, or will it be the result of all cumulative effects? We simply do not know. Thus, as previously mentioned, USFWS prefers to take the "precautionary approach" when addressing issues such as wind development – especially in light of such a poor understanding about wind energy's impacts on wildlife and their habitats.

The Department of Interior strongly supports renewable energy, including wind development, but the Service wants to ensure that it is bird-, bat- and habitat-friendly. We strongly encourage wind proponents to work at the get-go with the nearest USFWS Ecological Services Field Office in the proposed development area where they hope to build, prior to the completion of a land-owner agreement, approval of a power-purchase contract, and the application or receipt of a bank loan. Very few companies approach the Service early on to address potential impacts from wind development. This is further exacerbated by the fact that the Service lacks a strong Federal nexus on private land. The exception regarding a Federal nexus on private land is Section 404 of the Clean Water Act. However, unless there is a Federal permit, Federal funding, or the project is on Federal property, ESA Section 7 does not apply and ESA Section 10 (i.e., development of a Service-approved Habitat Conservation Plan through the NEPA public review process to acquire a "takings permit") is voluntary on the part of the proponent. MBTA is a strict liability statute, there is no consultation process, and the Act is only applicable after a "take" has occurred. The Bald and Golden Eagle Protection Act is also a strict liability statute, but a permit for "take" under otherwise legal activities is being finalized by the Service, but not yet implemented. From a proactive perspective, the Service's legal options are limited. To avoid or minimize impacts to trust wildlife resources, the Service released interim, voluntary guidelines for land-based commercial wind turbines in July 2003, open to two years of public comment and review. While the voluntary guidelines remain in place, and we encourage the industry to use them, the Interior Department convened an advisory committee to review and make recommendations regarding updates and changes to the Service's guidelines under the auspices of the Federal Advisory Committee Act (FACA). The FAC first met in February 2008, and is expected to continue to meet through the summer 2009 at which point it will provide a recommendation to the Service likely by October 2009 on what the FAC thinks the guidelines should contain.

Once a recommendation is received from the FAC, the Service will designate a committee to review the FAC document to ensure it meets trust responsibilities, statutory muster, and is practical and applicable. The committee will revise the document, as necessary, before it undergoes Service final review. Next, all affected programs from the Service's regions, Washington Office, and the Department of Interior will review and approve the document. Finally, a notice of availability will be published in the *Federal Register* soliciting public review and comment on the Service's "final" draft guidelines. Once public comments are reviewed, final guidelines will be published – possibly some two years after USFWS receives the FAC recommendations. D. Stout is the Designated Federal Official on the Committee representing the Service and questions should be addressed to him (Dave_Stout@fws.gov) that cannot be answered from information posted on the Service's website.

Direct Impacts. Birds, including species from raptors, passerines, to waterbirds, have been documented killed during flight by rotating turbine blades (Stone 2007, Arnett et al. 2007, Kuvlesky et al. 2007, Kunz et al. 2007, Nicholson et al. 2005). New evidence is showing that birds and bats can also die from barotrauma – an apparent effect of sudden changes in air pressure from wind wake turbulence and blade tip vortices – that result in collapsed lungs, often with no sign of blunt force trauma (E. Arnett, Bat Conservation Internatl., 2008 pers. comm., P. Cryan 2009 pers. comm.). In addition, birds can collide with towers, nacelles, meteorological tower guy wires, power lines, the associated infrastructures, and "bird unfriendly" wiring can electrocute them. The Service has special concerns about project development on avifauna. 1) No full-season studies have yet been conducted in the East on avian-wind impacts. 2) The "take" of State and Federally-listed birds, *Birds of Conservation Concern*, Breeding Bird Survey declining species, "watchlist" species, imperiled waterbirds, and raptors that migrate along or below ridge lines are of growing concern. 3) Raptors and other species that nest in close proximity to wind facilities is another concern. 4) Known or suspected impacts of turbines on grassland songbirds (Leddy et al. 1999) and "prairie grouse" species such as Greater Prairie-chickens (*Tympanuchus cupido*), Gunnison's Sage Grouse (*Centrocercus minimus*), and Greater Sage-grouse (*C. urophasianus*; Manville 2004) raise further concerns. 5) The increasing height of land-based turbines now exceeding 130 m AGL (425 ft) and the increasing rotor swept areas exceeding 1.2 ha (3 ac) but projected to reach 1.6 ha (4 ac) by 2010 (B. Ram, wind consultant, 2007 pers. comm.) are putting turbines well within the zone of risk for migrating birds, not to mention impacts to birds during take-offs and landings. 7) The potential for a single-night, mass mortality event grows, especially when turbine numbers increase, mass migrations and inclement weather coincide, where wind facilities are placed in wildlife-unfriendly habitats, and where weather ceilings force birds down through a "migratory fall out" to well within rotor swept areas.

The major challenge facing the commercial wind industry is not only to make wind generation "clean" but also insure that it is "green." Importantly, that means not creating new problems for migratory birds while still trying to address challenges with our "carbon footprint" and greenhouse gas emissions. There are some preliminary but promising "tools" that are being assessed, some perhaps more pleasing to the industry than others. These include blade "feathering" (aka, idling) when bird and/or bat risk is high, changes in blade "cut-in" speed based on increased wind speed that blades begin to operate (benefitting both birds and bats), turbine setbacks from ridges, end-of-row turbine replacement with pylons, turbine pylon replacement in ridge dips, and other "tools." Research is still preliminary. Proper site selection continues to be critical.

Indirect Impacts. Habitats can be fragmented, disturbed, and disrupted, forcing out birds and bats, preventing breeding, altering behaviors, and possibly impacting populations – with recent evidence raised in Europe (Stewart *et al.* 2007). Indirect effects, although frequently difficult to quantify, can include 1) reduced nesting/breeding densities; 2) loss of population vigor and overall density; 3) habitat and site abandonment, and increased isolation between patches; 4) loss of refugia; 5) attraction to modified habitats; 6) behavior effects including stress, interruption, and behavioral modification; and 7) disturbance and displacement resulting in habitat unsuitability. As the industry grows, these indirect effects may also become cumulative. Both direct and indirect effects could become additive to normally compensatory mortality – a scenario we wish to avoid.

Habitat fragmentation is of considerable concern for grassland songbirds – the suite of avifauna now in the greatest overall decline – not to mention sage-steppe obligate songbirds and "prairie grouse" species, in addition to other suites of birds and bats. Until very recently, most fragmentation studies had been based on research conducted at "surrogate" structures such as power lines, oil platforms, fences, and roads, with results then compared to possible impacts from commercial wind development (Manville 2004). That is changing with the wind industry funding multi-stakeholder studies of Greater Prairie-grouse-wind turbine effects in the Flint Hills, KS, area, and through other studies elsewhere.

USFWS currently has several concerns regarding the use of sound science in assessing risk to wildlife trust species and their habitats. One is the wind industry's general lack of research independence. Most of the pre- and post-construction monitoring and risk assessment reviews are conducted by consulting firms heavily dependent on wind companies and energy corporations to hire them. While they may be the most qualified to conduct the studies, this becomes the proverbial "double-edged sword" because there presently exists no agreed upon, scientifically validated monitoring protocols that could be used consistently and compared between different projects region- and nationwide. As a condition of site permitting, some states have monitoring requirements, but most states only suggest use of voluntary risk-assessment and monitoring methodologies, if that. Since the vast majority of wind development is currently on private lands, the USFWS lacks any strong federal nexus (e.g., ESA S. 10 is voluntary, MBTA has no consultation provisions and "take" occurs only after-the-fact, NEPA is not required, and CWA S. 404 has limitations) to regulate it. The transparency of research results conducted by wind industry consultants continues to be a recurrent frustration for USFWS – in part because of early-project industry confidentiality issues. It is our hope that the current situation will change. If a project is approved and is soon to be developed, results from pre-construction surveys and any risk assessments should become part of the public record, at the very least shared with the state and federal agencies responsible for protecting species and habitats. The same should hold true for results from post-construction evaluations. We continue to work with the industry and its consultants to develop consistent, robust, scientifically credible, and acceptable pre- and post-construction research protocols – ideally consistent between companies and consultants.

At this writing, positive recommendations are being suggested and discussed between members of the wind Federal Advisory Committee. Iberdrola Renewable Energy-USA worked proactively with the Service to develop a company-wide Avian and Bat Protection Plan (ABPP) modeled after the April 2005 avian protection plan (APP) template developed between the Service and the electric utility industry. Iberdrola's ABPP was publicly released in late 2008. Iberdrola is also working proactively with representatives from the Service's Office of Law Enforcement (OLE) and DMBM to develop a voluntary bird and bat mortality reporting form, much like > 33 electric utilities are presently voluntarily providing OLE for birds. This effort is primarily focused on dealing with incident-specific issues. Perhaps overall the wind industry will consider developing an industry-specific template for an ABPP, borrowing from the APP developed by the Avian Power Line Interaction Committee. The Service's goal is to make wind energy truly "green" – i.e., with the goal of avoiding or minimizing take and habitat disturbance – while significantly addressing the challenges avifauna and other wildlife face from the impacts of global climate change. The task is a daunting one but we're moving in the appropriate direction. Whether it's dealing with communication towers, wind turbines, power lines, or building windows, the Service will continue to work proactively with those industries, consultants, entities, conservationists, and stakeholders who collectively can help us resolve the growing impacts from increasing numbers of structures we are placing on the landscape. We strongly encourage all affected "stakeholders" to partner with us.

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Possible Effects of Electromagnetic Fields from Phone Masts on a Population of White Stork (*Ciconia ciconia*)

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Monitoring of a white stork population in Valladolid (Spain) in the vicinity of Cellular Phone Base Stations was carried out, with the objective of detecting possible effects. The total productivity, in the nests located within 200 meters of antennae, was 0.86 ± 0.16. *For those located further than 300 m, the result was practically doubled, with an average of* 1.6 ± 0.14. *Very significant differences among the total productivity were found* ($U = 240$; $p = 0.001$, *Mann-Whitney test). In partial productivity, an average of* 1.44 ± 0.16 *was obtained for the first group (within 200 m of antennae) and of* 1.65 ± 0.13 *for the second (further than 300 m of antennae), respectively. The difference between both groups of nests in this case were not statistically significant* ($U = 216$; $P = 0.26$, *Mann-Whitney Test U). Twelve nests (40%) located within than 200 m of antennae never had chicks, while only one (3.3%) located further than 300 m had no chicks. The electric field intensity was higher on nests within 200 m* (2.36 ± 0.82 *V/m) than on nests further than 300 m* (0.53 ± 0.82 *V/m). Interesting behavioral observations of the white stork nesting sites located within 100 m of one or several cellsite antennae were carried out. These results are compatible with the possibility that microwaves are interfering with the reproduction of white storks and would corroborate the results of laboratory research by other authors.*

Keywords Cellsites; Cellular phone masts; *Ciconia ciconia*; Electromagnetic fields; Microwaves; Nonthermal effects; Reproduction; White stork.

Introduction

Most of the attention on the possible biological effects of electromagnetic fields (EMF) has been focused on human health. People frequently use wildlife as biological indicators to detect the alterations in the ecosystems and in an urban

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habitat. The numeric tendency of the populations of birds is of particular interest in the conservation of nature [1].

The cellsite antennae emit a frequency of 900 or 1800 MHz, pulsed in very low frequencies, generally known as microwaves (300 MHz–300 GHz), similar to the radar spectrum. The cellsite ordinarily have 3 sectors, with 3 antennae that cover an angle of 120 degrees each [2–5]. Though they have many and varied outputs, at a distance of 50 m, the power density is about $10\,\mu W/cm^2$ [2], while at distances of 100 m at ground level it measures above $1\,\mu W/cm^2$ (personal observation). Between 150 and 200 m, the power density of the main lobe near the ground is typically of some tenth of $1\,\mu W/cm^2$ [3].

In real life, living organisms are exposed to variable levels of electromagnetic fields (radiofrequencies), according to the distance from the cellular bases stations, the presence of passive structures to either amplify the waves (e.g., the metallic structures) or to shield them (buildings or other obstacles), the number of transmission calls within the transmitters and their position with relationship to the orientation of the antenna [2].

Animals are very sensitive electrochemical complexes that communicate with their environment through electrical impulses. Ionic currents and electric potential differences exist through the cellular membranes and corporal fluids [6]. The intrinsic electromagnetic fields from the biological structures are characterized by certain specific frequencies that can be interfered with by the electromagnetic radiation, through induction and causing modification in their biological responses [3]. Animals exposed to the EMF can suffer a deterioration of health, changes in behavior [7, 8], and changes in reproductive success [9, 10].

The low intensity pulsed microwave radiation from cellsites produces subtle athermal influences in the 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. "Windows" exist in whereby EMFs produce biological effects at specific frequencies (window effect) [11]. Some effects are manifested exclusively with a certain power density [12], while others are manifested after a certain duration of the irradiation, which indicates long-term cumulative effects [13]. During lingering exposure, the effects can change from stimulant to inhibition, depending on the pulse shape [14, 15], the duration, development, and differentiation and the physiologic condition or health of the receiving organism [16], and their genetic predisposition [17]. These waves seem to cause different, and even contrary effects, depending on their frequency, intensity, modulation, pulses or time of exposure [12, 16, 18]. The pulsed waves (in bursts) and certain low frequency modulations, produce great biological activity [14, 15, 18]. The dose-response relationships (athermal) are nonlinear [19].

Research has shown such effects on the living organisms at molecular [12] and cellular levels [20] on immune processes [21], in DNA [22], on the nervous, cardiac, endocrine, immune, and reproductive systems [16, 23–28], modification of sleep and alteration of the cerebral electric response (EEG) [29], increase of the arterial pressure and changes in the heart rhythm [30], and an increase in the permeability of the blood brain barrier [31].

The objective of this study was to investigate if the phone mast cellsites caused effects in wild birds similar to the laboratory studies, and studies carried out on people exposed to this radiation [3, 5, 32–35].

Materials and Methods

For monitoring the breeding success of the white stork population, nests ($n = 60$) were selected and visited from May to June of 2003. The difficulty of the investigation in the field, (and when studying wild species) does not allow one to control all variables as in the laboratory; however, the selected nests had similar characteristics. They were located in the roof of churches and buildings inside urban nuclei in Valladolid (Spain). (The nests on trees and other natural supports or outside the urban nuclei were never studied.) Since the cellsite radiations are omnipresent, very few places exist with an intensity of 0 V/m near inhabited nuclei. For that reason, nests were chosen that were exposed at very high or very low levels of electromagnetic radiation, depending on the distance from the nests to the antennas.

The nests were selected and separated in two categories:

a) Nests ($n = 30$) located within 200 m of one or several cellsite antennae (GSM-900 MHz and DCS-1800 MHz), placed in masts and in the roof of the buildings at 15–30 m high.
b) Nests ($n = 30$) located further than 300 m of any cellsites.

The nest were observed using a prismatic Zeiss 8 × 30 and a "Leika" 20-60 X telescope. The number of young were counted.

For the analysis of the results of the reproduction, two indexes were used:

1) the total productivity (number of young flown by each couple, including nests with zero chicks).
2) the partial productivity (number of young flown by couples with some chicks, excluding nests with zero chicks).

To compare the breeding success of both groups of nests a nonparametric test was applied (Mann-Whitney test U).

Also, we measured the electric field intensity (radiofrequencies and microwaves) in V/m, using a "Nuova Elettronica" device Model LX 1435 with 10% sensitivity, from a unidirectional antenna (range: 1 MHz–3 GHz). Keeping in mind the inaccessibility of the nests, the measurements were made in their vacinity under similar conditions, recording the reproducible values obtained when directing the antenna of the device toward the cellsite antenna in line of sight.

Between February 2003 and June 2004, we carried out 15 and 10 visits, respectively, to 20 nests located within 100 m of one or several cellsite antennae to observe the behavior of the species. The visits covered all the phases of breeding, from construction of the nest, until the appearance of young storks exercising their wings and practicing flight.

Results

Table 1 presents the number of young and electric field intensity (V/m) of each studied nest.

The total productivity, in the nests located within 200 m of antennae was 0.86 ± 0.16. For those located further than 300 m, the result was practically doubled, with an average of 1.6 ± 0.14 (Table 1). Both groups showed very significant differences in the breeding success ($U = 240$; $P = 0.001$, Mann-Whitney Test U).

Table 1
Intensity of electric field, total and partial productivity in the nests within 200 m and further than 300 m to the phone mast

Nests within 200 m			Nests further than 300 m		
Nest	Number of young	EMF (V/m)	Nest	Number of young	EMF (V/m)
1	2	0.8	1	1	0.4
2	2	0.6	2	2	0.7
3	0	0.8	3	1	1.3
4	3	1.5	4	1	1.1
5	1	1.7	5	1	0.6
6	2	2.9	6	3	0.4
7	1	3.1	7	2	0.6
8	1	1.3	8	2	0.7
9	1	1.3	9	3	0.6
10	1	2.8	10	1	0.7
11	1	1.8	11	2	0.8
12	3	3.2	12	2	0.3
13	1	1.6	13	3	0.1
14	0	2.7	14	1	0.6
15	0	2.3	15	2	0.5
16	0	2.7	16	3	0
17	0	2.5	17	2	0.3
18	0	3.5	18	1	0.8
19	0	3.5	19	2	0.2
20	0	2.7	20	0	0.8
21	0	2.9	21	2	0.2
22	2	3.2	22	1	0.6
23	0	2.5	23	1	0.5
24	1	2.6	24	1	0.7
25	1	2.4	25	1	1.4
26	0	2.2	26	2	0.1
27	1	2.6	27	1	0.1
28	1	3.1	28	2	0.2
29	1	3.1	29	1	0
30	0	3.0	30	1	0.6
Mean EMF		2.36			0.53
Total productivity		0.86		1.6	
Partial productivity		1.44		1.65	
Nests without young		12 (40%)		1 (3.3%)	

In partial productivity in average of 1.44 ± 0.16 was obtained for the first group (within 200 m of antennae) and 1.65 ± 0.13 for the second (further than 300 m of antennae) respectively. The difference between both groups of nests in this case was not statistically significant (U = 216; P = 0.26, Mann-Whitney Test U).

Twelve nests (40%) located within 200 m of the antennae never had any chicks, while only one (3.3%), located further than 300 m, never had chicks.

The electric field intensity was higher on nests within 200 m (2.36 ± 0.82 V/m) that on nests further 300 m (0.53 ± 0.82 V/m) (Table 1).

The results of the findings and interesting behavioral observations of the white stork nesting sites located within 100 m of one or several cellsite antennae and on those that the main beam impacted directly (EFI > 2 V/m) included young that died from unknown causes. Also, within this distance, couples frequently fought over the nest construction sticks and failed to advance the construction of the nests. (Sticks fell to the ground while the couple tried to build the nest.) Some nests were never completed and the storks remained passively in front of cellsite antennae.

Discussion

The effects of athermal microwaves on birds have been well known for more than 35 years [36, 37]. Some authors obtained beneficial effects in the production of insect eggs and exposed birds, but found that the mortality was doubled [38]. In hen experiments, problems of health and a deterioration of the plumage arose, while in the autopsies, leucosis and tumors of the central nervous system appears [39]. Giarola and Krueger [40] obtained a large reduction of the rate of growth and also a reduction of the adrenal glands, in exposed chickens. Kondra et al. [41] obtained an increase in the frequency of ovulation of exposed birds, and a bigger production of eggs but with less weight, proposing that the pituitary gland was stimulated. Other authors also have obtained effects reducing the rate of growth in chickens and rats, reduction in the production of eggs in hens exposed to microwaves of different frequencies and intensities, increase of fertility, and a deterioration of the quality of the eggshell at certain frequencies [42]. An increase in the embryonic mortality of chickens also has been found [15, 17, 43, 44]. These microwave effects are athermal [45]. Recently, it also has been demonstrated that the microwaves used in cellphones produce an athermal response in several types of neurons of the nervous system in birds [46] and that they can affect the blood brain barrier as has been observed in rats [47].

Birds are especially sensitive to the magnetic fields [48]. The white stork (*Ciconia ciconia*) build their nests on pinnacles and other very high places with high electromagnetic contamination (exposed to the microwaves). Also, they usually live inside the urban environment, where the electromagnetic contamination is higher, and remain in the nest a lot of the time, for this reason the decrease on the brood can be a good biological indicator to detect the effects of these radiations.

The results indicate a difference in total productivity but not in partial productivity between the near nests and those far from the antennae. This indicate the existence of nests without chicks, or the death of young in their first stages in the nests near cellsites (40% of nest without young, compared to 3.3% in nests further 300 m). Also, in the monitoring of the nests near to cellsite antennae, some dead young were observed and several couples never built the nest.

In previous studies in Valladolid, the results of productivity were generally higher than those obtained in this study and less nests appeared without young (Table 2).

Consistent with these results, the microwaves could be affecting one or several reproductive stages: the construction of the nest, the number of eggs, the embryonic

Table 2
Results of censuses carried out in Valladolid (Spain).

Year	Number of visited nests	Total productivity	Partial productivity	Couples without young(%)	References
1984	113	1.69	2.13	7	[65]
1992	115		1.93	5.2	[62]
1994	24	1.84		7.6	[63]
2001	35		2.43		[64]
2003 (<200 m)	30	0.83	1.44	40	This study
2003 (>300 m)	30	1.6	1.65	3.3	This study

development, the hatching or the mortality of chicks in their first stages. The faithfulness of the white stork to nest sites can increase the effects of the microwaves. A Greek study [49] relates to a progressive drop in the number of births of rodents. The mice exposed to 0.168 $\mu W/cm^2$ become sterile after 5 generations, while those exposed to 1.053 $\mu W/cm^2$ became sterile after only 3 generations. The interaction seems to take place through the central nervous system more than on the reproductive gland directly. Other studies find a decrease of fertility, increase of deaths after the birth in rats and dystrophic changes in their reproductive organs [16]. A recent study shows a statistically significant high mortality rate of chicken embryos subjected to the radiation from a cellphone, compared to the control group [43]. EMF exposure affected the reproductive success of kestrels (*Falco sparverius*), increasing fertility, egg size, embryonic development and fledging success but reduced hatching success [10]. An increase in the mortality [50] and the appearance of morphological abnormalities, especially of the neural tube [14, 15, 17] has been recorded in chicken embryos exposed to pulsed magnetic fields, with different susceptibility among individuals probably for genetic reasons. It is probable that each species, even each individual, shows different susceptibility to the radiation, since the susceptibility depends on the genetic bias, and of the irradiated living organisms physiologic and neurological state [4, 51]. Different susceptibility of each species also has been proven in wild birds exposed to CEM from high-voltage powerlines [9]. When the experimental conditions (power density, frequency, duration, composition of the tissue irradiated, etc.) change, their biological effects also change [25, 52]. Microwaves have the potential to induce adverse reactions in the health of people [2–5, 34, 35, 47]. Although the power output differs per site and type of transmitter, at more than 300 m distance from the antennas, most of the symptoms recorded in people diminish or disappear [34, 35]. It also has been pointed out that below 0.6 V/m the effects on the people disappear (Salzburg resolution).

Since, we cannot see symptoms for white storks, it is necessary to use objective variables such as the Total and Partial Productivity, and other characteristics of behavior (nonconstruction of nest, sticks fall, etc.). We recommend electromagnetic contamination in the microwave range be considered a risk factor in the decline of some populations, especially urban birds, especially when exposed to higher radiation levels. Because of their thinner skull, their great mobility and the fact that they use areas with high levels of microwave electromagnetic radiation, birds are very good biological indicators. The freedom of movement of birds and their habit of settling in the proximity and even on the cellsites, makes them potentially susceptible to such effects. Small organisms (children, birds, small mammals, etc.) are especially vulnerable, as absorption of microwaves of the frequency used in mobile telephones is greater as a consequence of the thinner skull of a bird, the penetration of the radiation into the brain is greater [2, 49, 53, 54].

Several million birds of 230 species die annually from collisions with the masts of telecommunication facilities in United States during migration [55]. The cause of the accidents has yet to be proven, although one knows that they mainly take place during the night, in fog, or bad weather. The birds use several orientation systems: the stars, the sun, the site-specific recognition and the geomagnetic field [48]. The illumination of the towers probably attracts the birds in the darkness, but it is possible that the accidents take place in circumstances of little visibility, because at the time, other navigational tools are not available. The perception to the terrestrial magnetic field can be altered by the electromagnetic radiation from the antennae. The reports of carrier pigeons losing direction in the vicinity of cellsites are numerous, and more investigation is necessary.

In the United Kingdom, where the allowed radiation levels are 20 times higher than those of Spain, a decline of several species of urban birds has recently taken place [56], coinciding with the increasing installations of cellsites. Although this type of contamination is considered at the present time by some experts as the most serious [4], inspection systems and controls have never been developed to avoid their pernicious effects on living organisms. Some of the biological mechanisms of the effects of these waves are still ignored [12], although the athermal effects on organisms have been sufficiently documented. The telephone industry could be taking advantage of the complexity of the biological and physical processes implied, to create an innocuous atmosphere, repeatedly denying the existence of harmful effects in living organisms. For this reason the reports related to animals are of special value, since in this case it can never be alleged that the effects are psychosomatic [3].

Future investigation should be carried out with long-term monitoring of the breeding success, of the sleeping places and of the uses of the habitat for species more vulnerable to the microwaves. Of special interest should be investigations that try to make correlations with the radiofrequency electromagnetic field measurements. Field studies investigating populations of urban parks and territories surrounding cellsites should be a high-priority. A radius of 1 sq K and the layout of concentric lines at intermediate distances can be useful to investigate differential results among areas depending on their vicinity and the radiation levels. We consider that the birds most affected from the microwave electromagnetic contamination could be:

1) those bound to urban environments with more sedentary customs, in general those that spend more time in the vicinity of the base stations;
2) those that live or breed in high places, more exposed to the radiation and at higher power density levels;
3) those that breed on open structures where the radiation impacts directly on adults and chicks in the nest;
4) those that spend the night outside of holes or structures that attenuate the radiation.

In far away areas, where the radiation decreases progressively, the chronic exposure can also have long term effects [13, 49]. Effects from antennas on the habitat of birds are difficult to quantify, but they can cause a serious deterioration, generating silent areas without male singers or reproductive couples. The deterioration of the ecosystem can also take place from the impact of the radiation on the populations of invertebrate prey [54, 57, 58] and on the plants [59].

Bioelectromagnetics is historically a frontier discipline. Controversy is frequent when the scientists recognize serious effects on health and on the environment that cause high economic losses. Independent investigators state the necessity of a drastic reduction of the emmitted power levels on people and the ecosystems and that it is technically viable although more expensive for the industry [4, 22, 60]. Our opinion is that areas of continuous use should never exist at the height of the antennas either inside the beam or within a radius of several hundreds meters. The restriction to exposure to fauna presents special complexity; the main reason for the drastic reduction in the emission power of the antennae is presented as the only viable and effective solution to prevent these effects. Some authors have already propose that we are withessing a paradigm change in biology [61].

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A Possible Effect of Electromagnetic Radiation from Mobile Phone Base Stations on the Number of Breeding House Sparrows (Passer domesticus)

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A possible effect of long-term exposure to low-intensity electromagnetic radiation from mobile phone (GSM) base stations on the number of House Sparrows during the breeding season was studied in six residential districts in Belgium. We sampled 150 point locations within the 6 areas to examine small-scale geographic variation in the number of House Sparrow males and the strength of electromagnetic radiation from base stations. Spatial variation in the number of House Sparrow males was negatively and highly significantly related to the strength of electric fields from both the 900 and 1800MHz downlink frequency bands and from the sum of these bands (Chi^2-tests and AIC-criteria, $P < 0.001$). This negative relationship was highly similar within each of the six study areas, despite differences among areas in both the number of birds and radiation levels. Thus, our data show that fewer House Sparrow males were seen at locations with relatively high electric field strength values of GSM base stations and therefore support the notion that long-term exposure to higher levels of radiation negatively affects the abundance or behavior of House Sparrows in the wild.

Keywords Antenna; Bird; Electromagnetic radiation; GSM base station; Non thermal effect.

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Introduction

Mobile phones, also called cellular phones or handies, are now an integral part of modern life. The widespread use of mobile phones has been accompanied by the installation of an increasing number of base station antennas on masts and buildings. GSM base stations emit electromagnetic fields at high frequencies in the 900 and 1800 MHz range (= downlink frequency bands), pulse modulated in low frequencies (Hyland, 2000). In recent years, increased public awareness and scientific research have questioned to what extent the non thermal exposure to low-intensity electromagnetic fields may affect the health, reproduction, well-being and behaviour of humans and other organisms. There is an active and, as yet, unsettled controversy about current safety standards. Some researchers and national committees advised more stringent safety standards, based on experimental data with reported biological effects from (chronic) non thermal exposures (Hyland, 2000; Belyaev, 2005a, b).

There are studies showing frequency-specific biological effects, and studies demonstrating that a high frequency signal modulated at certain low frequencies, or a signal that is pulsed, has more harmful effects than an unmodulated, steady carrier. These so-called 'window effects' greatly complicate any attempt to understand the relationship between electromagnetic radiation and health (Adey, 1981; Hyland, 2000; Lai, 2005; Belyaev, 2005a).

Public and scientific concern were also raised by results of some epidemiologic studies that examined the effects of long-term exposure on humans living near mobile phone base stations. A growing number of studies point to the existence of effects, ranging from changes in cognitive performance and sleep disturbances to serious illness and disablement, with even higher cancer rates (Santini et al., 2002; Navarro et al., 2003; Bortkiewicz et al., 2004; Eger et al., 2004; Wolf and Wolf, 2004; Hutter et al., 2006; Abdel-Rassoul et al., 2006).

Short-term laboratory experiments used mice, rats, chickens and other birds as study models to better understand the possible implications of electromagnetic fields on organismal functioning. In many studies however, 'mobile communication-like' signals were investigated that in fact were different from the real exposures in such aspects as intensity, carrier frequency, modulation, polarisation, duration and intermittence (Belyaev, 2005a, b; Lai, 2005).

Studies of the effects of exposure to electromagnetic fields on populations of wild birds can provide further insights into the potential impacts on animal and human health (Fernie and Reynolds, 2005). Birds are candidates for being good biological indicators for low-intensity electromagnetic radiation: they have thin skulls, their feathers can act as dielectric receptors of microwave radiation, many species use magnetic navigation, they are very mobile and possible psychosomatic effects are absent (Bigu-del-Blanco and Romero-Sierra, 1975; Balmori, 2005). Field studies of wild populations can also reveal possible effects of long-term exposure to radiation from GSM base stations. In addition, species like the House Sparrow (*Passer domesticus*) are especially of interest because a large proportion of the birds use higher breeding height locations like roof spaces (Wotton et al., 2002) where potentially higher levels of base station radiation are present.

Here we report results of a preliminary study that explored putative effects of electromagnetic radiation emitted by mobile phone base stations on the number of House Sparrows during the breeding season. Specifically, we examined small-scale geographic variation within each of six study areas in both the number of birds and the strength of electromagnetic radiation. If electromagnetic fields from GSM base stations have adverse effects on bird populations, this should result in a decreasing number of House Sparrows with increasing levels of radiation.

Materials and Methods

Data collection

We determined, during the spring of 2006, the number of House Sparrow males and the strength of electromagnetic radiation from mobile phone (GSM) base stations at 150 locations that were distributed over six residential areas in the region of Gent – Sint-Niklaas (province of East Flanders, Belgium). The study areas were similar in overall appearance, with abundant hedges, bushes and other vegetation between the houses, and with one or more GSM base stations nearby.

The 150 study locations were selected in advance as points on a map (ArcGIS). All locations were situated along small roads within the residential areas and were at variable distances from the nearest GSM base station (mean = 352 m, range = 91 - 903 m, about 90% at 100 - 600 m). The number of locations, and study dates, within each area were: Lokeren - Eksaarde (N = 19; April 9), Lokeren - Spoele (N = 27, April 15), Lokeren - Bergendries (N = 17, April 17), Sint Niklaas - Clementwijk (N = 25, April 20), Gent- Wondelgem (N = 38, April 25) and Gent - Mariakerke (N = 24, April 26).

At each location, a point count of five minutes (see 'point transect count' in Bibby et al., 2000; Hustings et al., 1985) was made of the number House Sparrow males that were singing or otherwise visible within a distance of ca. 30 m. Sightings of birds were done with binoculars (Swarovski EL 10x42). Counts were restricted to the morning hours (7-11h), when male House Sparrows are most active (Hustings et al., 1985; Van Dijk, 2004), on days with favourable weather conditions (no rain, little wind, sunny, normal temperatures).

Simultaneously, we measured the maximum value (peak hold) of the electric field strength (in V/m) from the downlink frequencies of GSM 900 MHz (925-960 MHz) and GSM 1800 MHz (1805-1880 MHz) base station antennas. Measurements at each location were made during two minutes for each frequency band. The electric field strength was measured using a portable calibrated high-frequency spectrum analyser (Aaronia Spectran HF-6080; typ. accuracy ± 3 dB) with calibrated EMC directional antenna (HyperLOG 6080; logarithmic-periodic). To measure the maximum radiation values, the EMC antenna was turned around in all directions.

Additional antennas for the new UMTS-system are now being installed on several existing base stations in Belgium. Therefore, at several locations within each study area, the electric field strength from the downlink frequencies of UMTS antennas (2110-2170 MHz) was also checked, but no significant signals were found. Consequently, the UMTS variable was not taken into account for further analysis.

Data analyses

The sum (Egsm) of the measured GSM 900 MHz (Egsm900) and 1800 MHz (Egsm1800) electric field strength values was calculated using the formula: $Egsm = \sqrt{Egsm900^2 + Egsm1800^2}$ (Electronic Communications Committee, 2003). Prior to all analyses, the electric field strength variables were logarithmically transformed to achieve normality of their frequency distributions.

We explored relations between the number of House Sparrow males (dependent variable) and each of the three electric field strength variables. As the dependent variable consists of count data and is hence discontinuous, standard regression (or correlation) techniques are inappropriate. Instead, we used Poisson regressions (i.e., generalized linear models) with a log link function to examine putative relationships. Preliminary analyses indicated that significant variation among the six study areas was present for all variables (ANOVA, $P < 0.001$). Therefore we included "area" as a categorical factor in all models and considered it to be a proxy for all unknown, and hence unmeasured variables causing among area variation in the number of House Sparrows (e.g., habitat characteristics, food availability, temporal differences among censuses). Statistical analyses were done with S-PLUS v. 6.2.

Results

The number of House Sparrow males varied between zero and four at the different locations. The measured electric field strengths were seldom higher than 1 V/m, and most often well below that value (Table 1).

To explore the putative effects of area, electric field strength and their interaction on the number of House Sparrows, we performed separate analyses for each of the three radiation variables. As no significant interaction effect between area and electric field strength was detected in any of the three analyses (Chi²-tests and AIC-criteria, $P > 0.20$), we excluded the interaction term from further treatments. The final regression models were highly similar for the three electric strength variables. They revealed significant variation among study areas (Chi²-tests, $P < 0.001$), and a highly significant negative effect of electric field strength on the number of House Sparrow males (Chi²-tests and AIC-criteria, $P < 0.001$; Figure 1). Estimates of the scaled deviance (1.06 – 1.14) were very close to 1, and examination of the regression residuals revealed no clear patterns or deviations from normality. These observations indicate an adequate fit of the models to the data.

Table 1

Summary statistics (mean, 95% confidence interval, range) of the number of House Sparrow males and electric field strength variables in the six study areas. Means and confidence limits of the radiation variables were calculated after back-transformation of the logarithmically transformed data; the confidence intervals are therefore asymmetrical around the mean

Study area		Number of House Sparrow males	E_{gsm900} (V/m)	$E_{gsm1800}$ (V/m)	E_{gsm} (V/m)
1: Lokeren - Eksaarde	mean	1.5	0.153	0.075	0.193
	95% CI	0.8 – 2.2	0.108 - 0.216	0.046 - 0.123	0.139 - 0.270
	Min - Max	0 – 4	0.036 - 0.494	0.015 - 0.333	0.052 - 0.505
2: Lokeren - Spoele	mean	1.9	0.084	0.083	0.130
	95% CI	1.5 – 2.3	0.059 - 0.120	0.058 - 0.120	0.091 - 0.183
	Min - Max	0 – 4	0.008 - 0.327	0.013 - 0.394	0.016 - 0.412
3: Lokeren - Bergendries	mean	0.8	0.245	0.017	0.247
	95% CI	0.3 - 1.3	0.186 - 0.323	0.009 - 0.031	0.187 - 0.327
	Min - Max	0 - 3	0.052 - 0.537	0.004 - 0.125	0.052 - 0.551
4: Sint Niklaas - Clementwijk	mean	1.0	0.130	0.056	0.148
	95% CI	0.6 - 1.4	0.098 - 0.173	0.039 - 0.082	0.111 - 0.197
	Min - Max	0 - 3	0.019 - 0.412	0.009 - 0.231	0.021 - 0.469
5: Gent - Wondelgem	mean	1.3	0.109	0.040	0.121
	95% CI	0.9 - 1.6	0.079 - 0.151	0.030 - 0.054	0.089 - 0.165
	Min - Max	0 - 4	0.016 - 1.006	0.009 - 0.321	0.022 - 1.056
6: Gent - Mariakerke	mean	0.8	0.043	0.080	0.160
	95% CI	0.3 - 1.2	0.024 - 0.078	0.049 - 0.130	0.107 - 0.240
	Min - Max	0 - 4	0.006 - 1.022	0.017 - 0.824	0.040 - 1.023

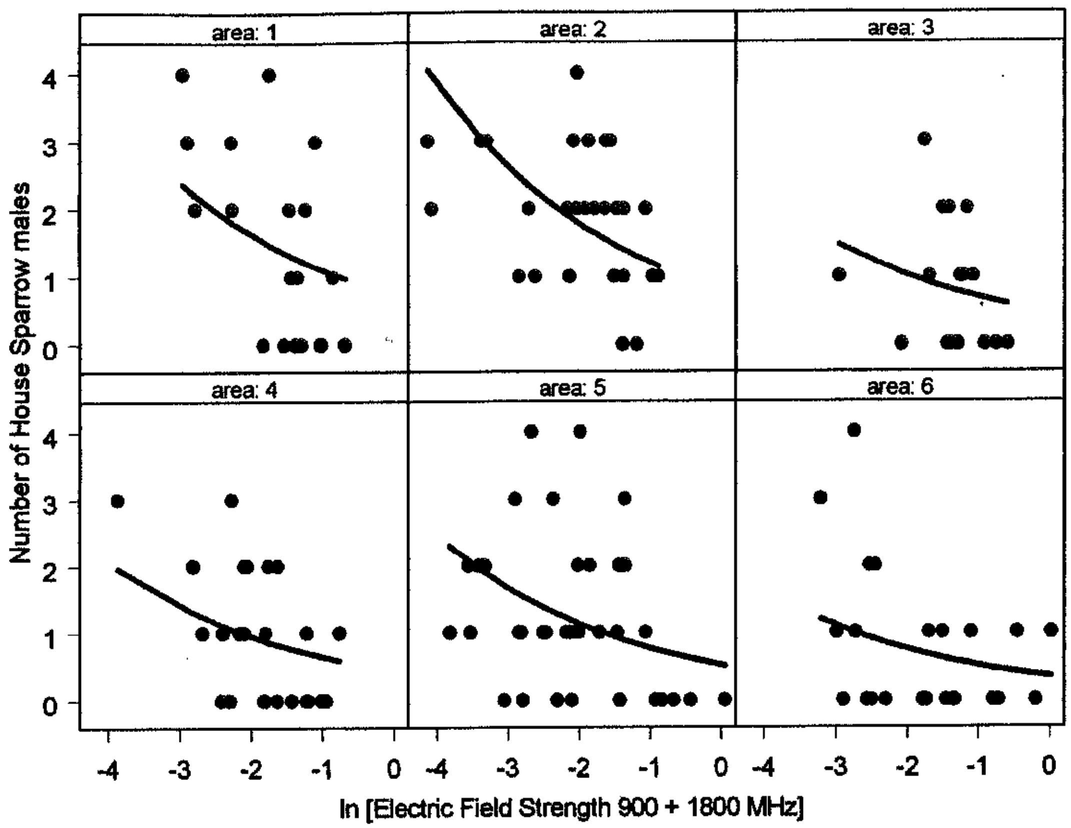

Figure 1. Scatterplots of the observed number of House Sparrow males as a function of the sum (Egsm) of GSM 900 MHz and GSM 1800 MHz electric field strength values (logarithmic scale) at the different locations within each of the six study areas. Regression lines were obtained by Poisson regressions and incorporated the effects of area and radiation intensity (see text).

We further explored the separate effects of electromagnetic radiation at the two frequencies by modelling the number of House Sparrow males as a function of area, electric field strength at 900 MHz, electric field strength at 1800 MHz, and their interactions. The final model retained included highly significant effects of area and the two electric field strengths (Chi^2-tests and AIC-criteria, $P < 0.001$) and a marginally significant interaction effect between both field strengths (Chi^2-test, $P = 0.02$). This strongly suggests that the electromagnetic radiations at both frequencies have complex additive effects on the number of House Sparrow males.

Overall, analyses indicated that the strength of all three radiation variables decreased with increasing distance to the nearest base station (F-tests, $P < 0.001$). We therefore examined whether the negative relation between the number of birds and strength of radiation was induced by variation among sampling locations in the distance to GSM base stations. Upon adding distance to the nearest base station as an additional factor to the regression models that included area and electric field strength, distance did not account for a significant portion of the residual variation (Chi^2-tests and AIC-criteria, $P > 0.50$). Conversely, when we forced distance as the first factor into the regression equations, both area and radiation strength were subsequently selected as highly significant factors (Chi^2-tests and AIC-criteria, $P < 0.001$).

Discussion

Our results indicate that spatial variation among sampling locations in the number of House Sparrow males was negatively related to the strength of electric fields emitted by GSM base stations. Importantly, this relation was highly similar among the six study areas, as evidenced by the non-significant interaction effects between area and electric field strength, despite differences among areas in both the number of birds and radiation levels. Moreover, the negative association was detected for electric field strengths from both the 900 and 1800 MHz frequency bands and from the sum of these frequency bands. Our analyses also revealed that the negative relation between the number of birds and strength of radiation was not a simple consequence of differences among sampling locations in distances to the nearest GSM base station. This can probably be attributed to variations in the orientation, position and number of antennas and to the shielding effects and multiple reflections from structures like buildings and trees, which affect local levels of exposure to electromagnetic radiation. Thus, our data show that fewer House Sparrow males were seen at locations with relatively high electric field strength values of GSM base stations and therefore support the notion that long-term exposure to higher levels of radiation negatively affects the abundance or behaviour of House Sparrows in the wild.

Nevertheless, our study should be considered as preliminary for several reasons. First, sampling locations were each visited only once, such that counts of the number of House Sparrow males and measurements of electric field strength are subject to some variation and estimation error. However, it is most likely that these errors are randomly distributed among locations. We also note that a single visit during the peak of the breeding season (April – May) is considered to be adequate to locate House Sparrow breeding territories (Hustings et al., 1985; Van Dijk, 2004). Second, because of the short study period, we ignore whether differences in bird counts reflect variation in abundance of breeding birds or in short-term behavioural responses like the tendency to sing. However, a decrease in singing intensity will result in a decrease of reproductive success and ultimately a decline of population size. Third, only the radiation from GSM base station antennas was measured. Probably, the distribution of possible other significant electromagnetic signals will be random, but due to the lack of measurements in other frequency bands (except for UMTS), this remains an object of further study. Fourth, as with all descriptive field studies, we cannot provide evidence for a causal relationship between radiation levels and the number of birds. Nevertheless, the fact that we found a highly similar pattern in each of the six study areas strengthens the possibility that the relationship is not a spurious one.

There are several unpublished and anecdotal reports about birds and mobile phone base stations, but we know of only one other published study that examined the effects of electromagnetic radiation from mobile phone base stations on wild bird populations. Balmori (2005) found a significantly lower number of White Stork (*Ciconia ciconia*) fledglings in nests exposed to relatively high electromagnetic radiation (2.36 ± 0.82 V/m) than in nests receiving lower levels of radiation (0.53 ± 0.82 V/m). Together with observations on aberrant behaviours of the adult birds, these results suggest that electromagnetic radiation interferes with reproduction in this wild population.

What could be the underlying mechanisms of the (putative) negative effects of radiation from GSM base stations on wild bird populations? Because all measured electric field strength values were far below what is required to produce heating as low as 0.5 °C (i.e., 10 mW/cm^2 or ca. 194 V/m; Bernhardt, 1992), the effects should be considered as non thermal at very low intensities.

Non thermal effects of microwaves on birds were reported already 40 years ago (Tanner, 1966; Tanner et al., 1967). Most studies indicate that exposure of birds to electromagnetic fields generally changes, but not always consistently in effect or in direction, their behaviour, reproductive success, growth, development, physiology, endocrinology, and oxidative stress (Wasserman et al., 1984; Grigor'ev et al., 2003; Fernie and Reynolds, 2005). Of special relevance within the context of our research are laboratory studies that demonstrate negative effects of electromagnetic radiation from mobile phones on the development and survival of bird embryo's (Farrel et al., 1997; Youbicier-Simo and Bastide, 1999; Grigoriew, 2003).

Bird feathers are known to act as dielectric receptors of high frequency electromagnetic fields and some experiments indicate that audiofrequency pulse-modulated high frequency fields may induce piezoelectric effects in the feathers (Bigu-del-Blanco and Romero-Sierra, 1975a, b). These results are important in view of the fundamental role that feathers play in the life of birds and in the influence of environmental factors on bird behaviour. Experiments also indicated that microwave radiation can have the same averse effects on birds in flight as those observed in caged birds (Romero-Sierra et al., 1969).

Several bird species also use magnetic navigation (Liboff and Jenrow, 2000; Muheim et al., 2006) and can become disorientated when exposed to weak (< 1/50 of geomagnetic field strength) high frequency magnetic fields (Ritz et al., 2004; Thalau et al., 2005). The available evidence concerning magnetoreception suggests that birds use a radical pair mechanism for a chemical compass, and a mechanism based on magnetite particles (Wiltschko and Wiltschko, 2005; Mouritsen and Ritz, 2005). Magnetite is an excellent absorber of microwave radiation at frequencies between 0.5 and 10.0 GHz through the process of ferromagnetic resonance (Kirschvink, 1996), so that interaction with electromagnetic fields from mobile phone base stations might be possible.

In an experiment with Zebra Finches (*Taenopygia guttata*) that were temporary (10 minutes) stimulated with a pulsed electromagnetic field similar to the signal produced by mobile phones with carrier frequency 900 MHz, significant non thermal changes in the amount of neural activity by more than half of the brain cells were detected (Beasond and Semm, 2002). The effect did not appear tot be limited to magnetic sensory cells, but occurred in any part of the brain. The authors postulate that similar neural responses to different frequencies point toward a common mechanism of low frequency modulation, perhaps at the cell membrane. Such a stimulus might mimic a natural mechanism involved in cell communication. Although the peak electric field strength used in that experiment (0.1 mW/cm^2 = approx. 19 V/m; Beasond and Semm, 2002) was higher than the values measured in our study, results from other studies indicate that a long-term exposure at low intensities can produce the same effects as a short-term exposure at higher intensity (D'Andrea et al., 1986a, b; Lai, 2005; Belyaev, 2005a). This suggests that the non thermal effects of relatively weak electromagnetic radiation from mobile phone base stations can accumulate over time and have significant implications, as detected by several pilot epidemiological studies on humans (see Introduction).

Radiation from GSM base stations may also affect the local abundance of insects or other invertebrates and thereby indirectly influence the number of House Sparrows. Although adult House Sparrows are mainly seed-eaters, they need insects and other invertebrates to feed their young, such that it is likely that they will prefer areas with high abundance of invertebrates at the beginning of the breeding period. Several researchers have postulated that the lack of invertebrates might be an important factor in the reported decline of House Sparrow populations in urban areas (Wotton et al., 2002; Summers-Smith, 2003). Short-term exposure of pulsed mobile phone radiation with carrier frequency 900 MHz resulted in a 50-60 % decrease of the reproductive capacity of insects (Panagopoulos et al., 2004). Similar results were also found with microwave radiation at other frequencies (Bol'shakov et al., 2001; Atli and Unlu, 2006).

The results of our study suggest that long-term exposure to low-intensity (pulsed) electromagnetic radiation from GSM base stations may have significant effects on populations of wild birds. The exact mechanisms of these effects are as yet poorly understood. Given the potential importance that such effects may have on aspects of biodiversity and human health, more detailed studies in both the laboratory and the field are urgently needed to corroborate our results and to uncover the underpinning mechanistic relationships.

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Conspicuous behavioural abnormalities in a dairy cow herd near a TV and Radio transmitting antenna

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SUMMARY: In addition to a considerable reduction of milk yield and increasing occurences of health problems, behavioural abnormalities that have not yet been examined, have been observed over the last two years in a herd of dairy cows maintained in close proximity to a TV and Radio transmitting antenna. The evaluation of possible factors which could explain the abnormalities in the livestock did not disclose any factors other than the measurable high-frequency electromagnetic fields. An experiment in which a cow with abnormal behaviour was brought to a stable in a different area resulted in normalisation of the cow within five days. The symptoms returned, however, when the cow was brought back to the stable in close proximity to the antenna in question. In view of the previously known effects of electromagnetic fields it may be possible that the observed abnormalities are related to the electromagnetic field exposure.

Key words: transmitting antennas, electromagnetic fields, milk yield, behaviour, cow.

Introduction

Because of the ubiquitous usage of electric power and the increasing spread of high-frequency transmitters for mobile communication and TV & Radio broadcasting, humans and animals in highly industrialized countries are these days exposed to electrical and magnetic fields to a degree which exceeds the natural tension levels of relevant fields by a magnitude and presents a new influencing quantity in the evolutionary history of humans and animals (Katalyse 1994). For a long time the possibility of an influence of weak electrical and magnetic fields on the well-being of humans and animals has simply been ignored. The limits were only relating to acute cases of health impairment which can occur at some workplaces under extremely high exposure rates. The ever increasing knowledge of the biological effects of even weak electrical and magnetic fields as well as numerous epidemiological studies with the focus on a possible increase in the risk of cancer through field exposure have, however, led in the last ten to fifteen years to an altered discussion of the possible risk potential of such fields (Adey 1993; Hendee and Boteler 1994; Katalyse 1994; Meinert and Michaelis 1996; Robert 1993; Savitz 1995; Shaw and Croen 1993; Sobel et al. 1996; Wertheimer and Leeper 1994). As one can be protected well from electrical fields in contrast to magnetic fields, the effects of such fields on human and animal health are rarely the focus of scientific research. In comparison, low-frequency magnetic fields can practically penetrate any matter without being slowed down, and high-frequency electromagnetic fields and waves can cause biological effects - even in greater distance from their source – which are possibly connected to health risks (Katalyse 1994). Fields of this type which are a necessity of civilisation and have certain health effects are commonly known as "Electrosmog".

The question of a possible risk of cancer which today cannot be discounted mainly because of numerous findings based on experiments with animals (Liburdy and Löscher 1997; Löscher and Mevissen 1994), occupies the foreground of public debate about possible health risks through exposure to low-frequency magnetic or high-frequency electromagnetic fields. In addition, there are extensive indications of interactions of magnetic fields with the hormonal balance, biorhythm, immune system, nervous system, behavioural patterns and psychological functions, interactions which can have a detrimental effect on health (Katalyse 1994; Liburdy u. Löscher 1997; Löscher u. Liburdy 1998). In this connection it is often forgotten that not only humans but also pets and farm animals who are exposed can suffer such impairments to their health because of field exposure, for example in the vicinity of high tension pylons or transmitting antennas (Marks et al. 1995). Similarly to epidemiological studies on humans with field exposed workplaces the risk of breast cancer for hundreds living in apartments with high flux densities of low-frequency (60 Hertz) magnetic fields was seven times higher in comparison with animals that were not exposed (Reif et al. 1995), a finding that can be explained by the "Melatonin Hypothesis" of magnetic field effects (Löscher and Mevissen 1997).

A series of earlier studies looked at the effect of magnetic fields on farm animals. Lee et al. (1997) discovered that sheep which had been grazing in close proximity to a high tension mast, showed an impaired immune system. Examinations of dairy cows that had been exposed to magnetic fields resulted in inconsistent findings which ranged from no influence at all to a reduction in milk yield, changed milk composition and fertility problems (Algen and Hultgren 1985a, b, 1987; Amstutz and Miller 1980; Angell et al. 1990; Burchard et al. 1996; Marks et al. 1995; Martin et al. 1986). The predominant share of the examinations on dairy cows was conducted under exposure to low-frequency (50 or 60 Hertz) fields, whereas only few studies deal with the effect of high-frequency electromagnetic fields, for example in the vicinity of transmitting antennas.
A recently publicized study discovered a significant increase of micronuclei in erythrocyte in the blood of cattle grazing on a farm near a transmitting facility. This is an indication of a genotoxic effect of the exposure (Balode 1996).

In the case described by this study a farmer asked a veterinary department for help after he had experienced major problems with his herd of dairy cows since the previous year. The farm is situated in close proximity to a transmitting tower with several transmitters (see Table 1 and Figure 1). The problems with the herd described in the following started after several transmitters for mobile radio communication had been installed in addition to the already existing TV transmitting antennas. As the farmer himself and his family were experiencing considerable health problems since the additional transmitters were installed, and none of the medical tests conducted had shed any light on the source of these health problems, the farmer came to the conclusion that the high-frequency electromagnetic fields that were produced by these transmitters had to be the cause of the problems including the problems experienced by his dairy cow herd. The relevant veterinary department then conducted observational studies and research which were complemented by measurements of the electromagnetic fields, with its focus on the dairy cow herd.

Table 1: Transmitting antennas in close proximity of the farm (all installed in the TV tower of Figure 1)

Transmitting Antenna	Frequency	Performance
39 directional radio transmitters (Mean)	2.2 – 18.7 GHz	124 W
C-Net	461 MHz	34 W
D-Net	935 MHZ	25 W
B-Net	160 MHz	20 W
Cityruf	460 MHz	50 W
Eurosignal	87,361 MHz	2 kW

TV-Channel 2	510 MHZ	20 kW
TV-Channel 3	734 MHZ	20 kW
Modacom	427 MHz	15 kW

Ground Plan for Measurements outdoors

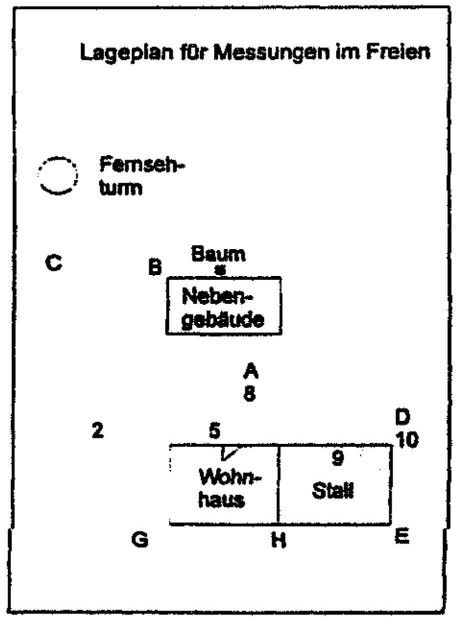

Figure 1: Ground plan for the measurements of electromagnetic fields in the vicinity of the transmitting antennas (for examples re the measurements see Table 2 and 3).

Observations of the dairy cow herd

Many of the biological effects and discussed health risks of electromagnetic fields are similar to the effects of chronic stress pressure (Blank 1995; Smith 1996). Apart from apparent problems caused by stress such as increased aborting without detectable causes, frequent fertility disorders in the form of an acyclic tendency and reduction in milk yield all of which have already been observed in herds grazing in close proximity to high tension lines (see overview in Burchard et al. 1996), the following abnormalities occurred in the affected dairy cow herd:

Most of the cows in this herd displayed conjunctivitis with heavy flood of tears (continuously wet cheeks) and itching (some cows rubbed their eye areas continuously against items in the stable within reach as well as against neighbouring cows).

Several animals were pushing their heads against the chest area of neighbouring cows turning their heads in the same direction (away from the transmitting antenna).
One cow showed very conspicuous behaviour by shuffling backwards and forwards moving her head continuously (Weaving). Resting phases alternated with the described behaviour which often lasted more than 30 minutes.

Cows in calf as well as dry cows that were put out on pasture land close to the farm, only grazed for a few minutes each time then taking "cover" from the transmitting tower in or behind an outbuilding.

Cows that have calved three or four times showed rapid decline. When these cows tried to get up their hind legs showed trembling and over time they found getting up increasingly difficult. The decline continued and led to their death after only a few weeks.

Conducted Examinations

1. Fodder analysis and feeding calculation

To exclude that a feeding fault had caused any metabolic disorders which in turn could be responsible for causing other health problems, a fodder analysis and feeding calculation was initiated by the relevant agricultural authority. The research and calculation yielded that the fodder was of high quality and that the amount of feed stuffs administered by the farmer was in relation to the performance of the dairy cows.

Figure 2: Typical turning of the head (away from the transmitting antennas) displayed by cows of the herd in question (see detailed description in text).

2. Autopsy of a perished dairy cow

The autopsy of a four-year-old cow that had died in the stable building and had previously displayed symptoms of the same illness as described above, provided the following result: Death from acute heart & circulatory collapse with bleeding from several organs. No indication as to the cause, in particular no acute or chronic inflammatory changes to organs. The autopsy was kindly performed by Dr. Geisel, Institute of Animal Pathology at the University of Munich.

3. Examination of aborted foetal material

The examination of aborted foetal material at the Landesuntersuchungsamt für das Gesundheitswesen Südbayern (Federal Examination Authority for the Health Service of Southern Bavaria) did not disclose any indication of pathogenic causes for aborting the foetus based on the microscopic and cultural examination and on the serological tests performed.

4. Switching stables

To obtain further indications with regard to the causes for the behavioural changes the dairy cow which displayed very obvious changes in behaviour and which was described under 3 in the section Observations of the dairy cow herd, and another dairy cow were separated from the original herd and joined another dairy cow herd in an identically partitioned stable which was approx. 20 kilometres away from the original location. After five days in the new stable the affected dairy cow did not show any of the conspicuous behavioural abnormalities any more. Both cows were relocated to the original stable after approximately two weeks. The previously affected cow displayed the described conspicuous behavioural abnormalities again after only a few days.

5. Measurement of the electromagnetic fields

Measurements of the electromagnetic fields in front of and on the farm property itself were conducted by the Bundesamt für Post und Telekommunikation (Federal Office for Postal Services and Telecommunication) and by the Abteilung für Elektronik und Radar der Universität der Bundeswehr München (Department of Electronics and Radar of the University of the German Federal Armed Forces in Munich). The most important results of these measurements are displayed in Table 2 and 3. The measurement values are considerably below the limits set out in the 26. Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung über elektromagnetische Felder; 26. BImSchV) (26. Ordnance/Decree** for the Implementation of the Federal Air Pollution Laws (Ordnance/Decree for electromagnetic fields; 26. BImSchV (Abbreviation for 26th Bundes-Immissionsschutzgesetz)) dated 16. December 1996.

Discussion

The health disorders and behavioural abnormalities described in this paper as well as the results of the conducted examinations point to the electromagnetic tension as the cause of the occurrences in the affected herd of dairy cows. The main problem in conducting an definitive assessment is the constant change in circumstances/ conditions because the farmer is forced to continue to run his farm and to keep the losses as small as possible. Therefore he tries to have cows which display the first signs of being affected such as worsening general condition after calving, either slaughtered early or taken to alternative grazing paddocks which are situated about 10 kilometres away from his farm. The relocation and exchange of dairy cows continuously creates a new situation because every cow reacts to the electromagnetic tension in an individual manner. Only a scientifically structured test of the affected dairy cow herd with set parameters could provide more definite findings in this case. Such a test of the affected herd is planned to clarify the causes of the observed behavioural abnormalities and health problems further. A causal relation could best be determined in this case by switching off the transmitting antennas for the mobile radio communication temporarily.

Table 2: Measurements of the electromagnetic field output in the attic storey of the farm house

Attic window	Frequency	Signal	Level (dBm)	Power density (µW/cm2)
closed	512.2	TV-2	- 12.8	0.044
closed	464.2	C-Network	- 43	0.00003
closed	936.2	D-Network	- 46.8	0.000051
closed	735.7	TV-3	- 15.8	0.04
open	511.4	TV-2	- 13.2	0.035
open	735.7	TV-3	- 7.6	0.26

Table 3: Measurements of the electromagnetic field output at different sites in the vicinity of and in the stable and living area (see Figure 1 for the measurement locations). The measurements were predominantly conducted at one frequency (512 MHz) because all other signals can be put in relation to the measurements inside the farm house (see Table 2) if we assume that the attenuation values through the wall of the building will not differ much within the relatively narrow frequency band (see Figure 1).

Measurement	Location	Frequency (MHz)	Level (dBm)	Power density (µW/cm2)
In the stable	Entrance (10)	512	- 9.6	0.08

In the stable	Middle part	512	- 24	0.003
In the stable	Rear part	512	- 26	0.002
Surrounding area	A	512	- 10.6	0.06
Surrounding area	B	512	0	0.7
Surrounding area	C	512	- 3.2	0.35
Surrounding area	F	512	- 10.8	0.06
In front of stable	D	512	- 3.8	0.36
Beside the stable	E	512	- 22.4	0.004
Beside the house	G	512	- 2	0.46
Behind the stable	H	512	- 13.4	0.03
Inside the house		735.7	- 15.8	0.04
In front of the house	5	88.8	- 4.8	0.006

Should the scheduled examination confirm the correlation described above between exposure to magnetic fields and health disorders or behavioural abnormalities then this would provide further indications that the limits set out in the 26. BlmSchV (Abbreviation for 26th Bundes-Immissionsschutzgesetz = 26th Federal Air Pollution Laws) are too high and require correction (see Karus u. Nießen 1996). In this case one has to take into consideration that even though the measurements for the different electromagnetic fields turned out to be below the limits set out in the 26. BlmSchV, interactions between the fields when animals and humans were exposed to them cannot be excluded because of the multitude of existing fields with different frequencies. Synergic interactions between electromagnetic fields with different frequencies have already been described on a cellular level (Löscher and Liburdy, 1998) and should not be neglected in future discussions regarding any limits of this kind.

After the above case had been published by the media and agricultural magazines more farmers have come forward describing similar cases. The above case description is mainly intended to alert the Veterinary Association to the obvious possibility of behavioural abnormalities and health problems caused by electromagnetic field exposure of animals.

Expression of Thanks
We would like to thank Prof. Klee (Veterinary Faculty of the Ludwig-Maximilians-University Munich) for the critical checking of this paper's manuscript.

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Responses of neurons to an amplitude modulated microwave stimulus

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Abstract

In this study we investigated the effects of a pulsed radio frequency signal similar to the signal produced by global system for mobile communication telephones (900 MHz carrier, modulated at 217 Hz) on neurons of the avian brain. We found that such stimulation resulted in changes in the amount of neural activity by more than half of the brain cells. Most (76%) of the responding cells increased their rates of firing by an average 3.5-fold. The other responding cells exhibited a decrease in their rates of spontaneous activity Such responses indicate potential effects on humans using hand-held cellular phones.

Keywords: Cellular telephone; Magnetic field; Health risk; Avian; Central nervous system

The postulated biological effects of electromagnetic fields are highly diverse, ranging from use of natural fields by animals for navigation to thermal cooking that occurs with strong fields such as those produced by microwave ovens [7]. It has been shown that even the weak fluctuations of Earth-strength magnetic fields influence the electrical activity of neurons and pineal cells and the synthesis of melatonin in birds and mammals [1,9,10], including humans [6]. Athermal effects have been the most difficult to explain because the mechanism by which they affect biological tissue is usually unknown. The question arises as to whether there is a particular sensitivity of the neural tissues of the brain to high frequency electromagnetic fields such as is produced by broadcast transmitters.

We tested the effects of electromagnetic radio frequency (RF) signals having a carrier frequency of 900 MHz, unmodulated and pulse modulated at 217 Hz with a duty cycle of 12.5% and a peak power density of 0.1 mW/cm^2. This stimulus was selected because it is similar to that used by the global system for mobile communication (GSM) telephone system. The calculated average specific absorption rate (SAR) of this stimulus for the test subjects was 0.05 W/Kg, based on the equations in Durney and coworkers [8]. The test subjects were 34 adult zebra finches (*Taenopygia guttata*), anesthetized with a mixture of ketamine (0.05 mg/g) and xylazine (0.01 mg/g) injected i.m. into the pectoralis major. The anesthetized bird was mounted in a nonconducting plastic holder. The bird and the holder were placed inside a tuned RF cavity (23.5 cm diameter, 100.5 cm long) made of perforated metal. We used a resonate cavity (length = 3λ) because the resulting electrical field was a standing wave and, therefore, was uniformly distributed within the cavity and was measured accurately at the demodulating stub. The resonant cavity was fitted with two tuned RF stubs (each 16.5 cm [λ/2] from opposite ends): one for emitting the signal and one for monitoring the frequency and power of the signal within the cavity. This arrangement resulted in the two stubs being 2λ from each other causing the signal at the demodulation stub to be synchronized in phase and intensity to the emitted signal. The entire bird was within the cavity and positioned such that the bird's head was at the center of the cavity. This position put the bird's head exactly 1λ from the emitting stub and the demodulating stub. Consequently, the signal the bird's head received was exactly the signal at both of those locations. To record from neurons in the brain of the bird, a small hole (4 mm diameter) was made through the skull. A glass microelectrode (tip diameter 1–2 μm) filled with a conducting solution

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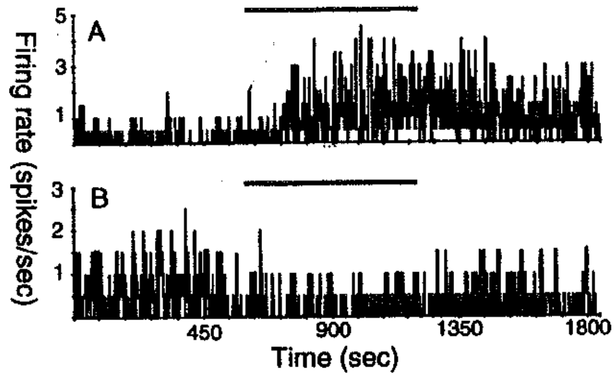

Fig. 1. Examples of neuronal responses in the zebra finch brain to stimulation of a 217 Hz, 12.5% duty cycle square wave modulated 900 MHz carrier signal: (A) simulation and (B) inhibition. The solid bar above each graph indicates the presence of the stimulating RF signal.

of physiological saline, to reduce conductivity, was slowly advanced into the brain through this hole until a spontaneously active nerve cell was detected. A silver reference electrode was inserted beneath the skin along the back of the head directly behind the glass microelectrode to complete the circuit. Arranging the electrodes along the long axis of the cavity prevented them from acting as a loop antenna and electrically stimulating the cells. Once a spontaneously active cell was located, it was tested with the stimulus. The protocol for all the testing procedures was a 10 min prestimulus period, a 10 min stimulus period, and a 10 min poststimulus period. The rates of the cell's activity during these three time intervals were compared to detect any effect of the stimulation. A responding cell was one that changed its firing rate during the stimulation by at least 10%.

The microwave stimulus signal was produced by an Amplifier Research amplifier (model 10W1000M7) driven by an HP 8350A sweep oscillator with an HP 83522A RF unit set for 900 MHz. Amplitude modulation of the signal was produced by a free running HP 3314A function generator set for 217 Hz square wave signal with a duty cycle of 12.5%. The output of the amplifier was switched between a matched load and the cable to the waveguide chamber by a single-pole, double-throw RF switch (HP 8761A). The switch was controlled by a digital signal from the computer program TIDA on an IBM-compatible microcomputer. The frequency and intensity of the emitted signal were monitored using an HP 5342A microwave frequency counter connected to the demodulator stub in the waveguide cavity. All power measurements were of peak power.

We recorded 133 spontaneously active units from 34 anesthetized adult zebra finches. The recording locations were in the cerebrum (Pars occipitalis and Pars parietalis) and Folia of the anterior cerebellum. Ninety-one units (69%) showed some response to the stimulation: 69 (52%) responded with excitation (Fig. 1A) and 22 (17%) responded with inhibition (Fig. 1B). The remaining 42 (31%) cells showed no discernible response. The cells showing excitation responded with increases in their rate of firing to the stimulation (mean rate during stimulation = 3.5 ± 0.30 [SE] times prestimulus rate; Fig. 2). Most of the inhibitory responses were small (mean rate during stimulation = 0.4 ± 0.07 times prestimulus rate; Fig. 2), in part because the cells were firing slowly before the stimulation. There was a significant difference among the firing rates of the three responses and the prestimulus firing rate (Kruskal–Wallis test: $H_c = 216.8$, $P < 0.001$, $\nu = 5$; see Fig. 3). Based on a non-parametric multiple comparison [13], the firing rates in the three response categories different from one another significantly ($P < 0.05$; $Q = 3.817$–4.341). There was no significant difference among the firing rates of the nonresponding cells during the prestimulus, stimulus, and post-stimulus periods ($P > 0.05$). All responses we recorded were to power densities of 0.1 mW/cm^2 (SAR = 0.05 W/Kg) and stronger (up to 0.5 mW/cm^2). The mean latency from the initiation of the stimulus to the start of the response was 104 ± 197 s, with the response lasting beyond the end of the stimulus period in half of the responding cells. The mean persistence beyond the end of stimulation was 308 ± 68 s, but there was no correlation ($r = 0.489$, $P > 0.05$) between the latency of the response and how long the cell continued responding beyond the end of the stimulus.

Three cells that responded to the modulated carrier were also tested with an unmodulated signal of the same carrier frequency. The power of the unmodulated signal was tested at two densities: one that equaled the peak power of the modulated stimulus and one that equaled the average power of the modulated stimulus. None of these cells exhibited a response to the unmodulated carrier. In addition to responses to the nominal stimulus, we also tested four cells that did not respond to the 0.1 mW/cm^2 pulsed signal with higher power densities

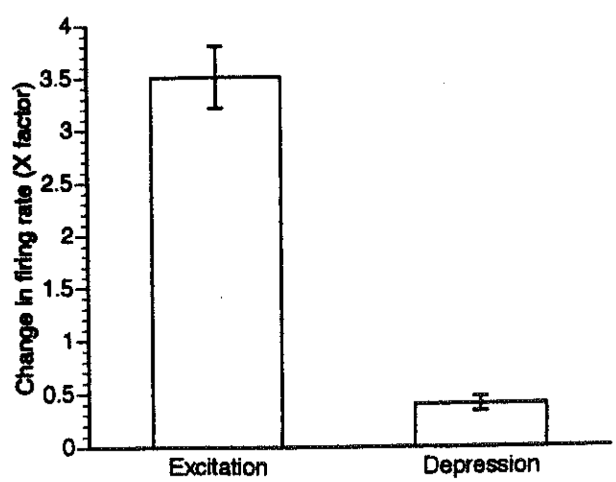

Fig. 2. Mean relative firing rates of cells that responded to the simulated GSM signal and were categorized as excitation or depression. The firing rates are relative to the cells' firing rates during the prestimulus period. The vertical bars indicate 1 standard error.

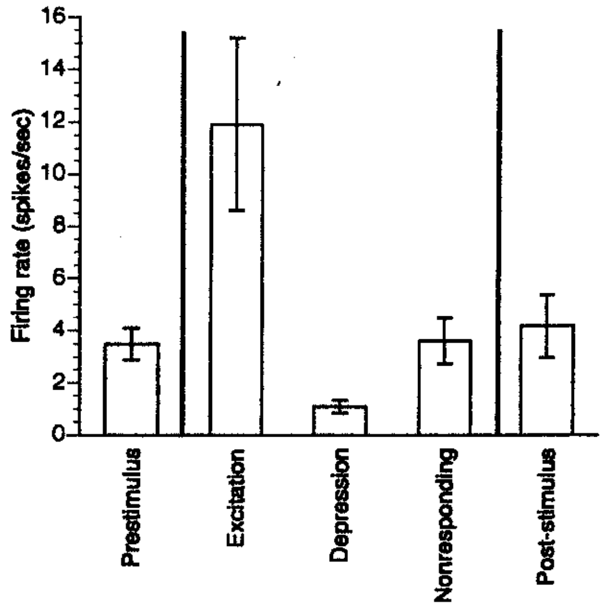

Fig. 3. Firing rates of zebra finch neurons during the prestimulus (10 min), stimulus (10 min), and poststimulus (10 min) periods. The poststimulus values are for the non-responding cells only because the responding cells often continued their response into the post-stimulus period (see text for details). The firing rates of the three responses differed significantly (Kruskal–Wallis test: $H_c = 216.8$, $P < 0.001$, $v = 5$). The vertical bars indicate 1 standard error.

(up to 0.5 mW/cm^2). Three cells did not respond to the stronger intensities, but one cell that did not respond to the 0.1 mW/cm^2 stimulus responded to an intensity of 0.3 mW/cm^2 with depression of its rate of activity.

One concern was that the electrodes themselves were acting as an antenna and stimulating the cells electrically. The arrangement of the active and reference electrode centered along the long axis of the waveguide chamber prevented them from serving as a loop antenna. In preliminary experiments we varied the positions of the electrodes to determine whether they could, in fact, act as an antenna. When the electrodes were not aligned longitudinally, the stimulus artifact was detected directly and observed on the oscilloscope display. Whether such a stimulus was strong enough to stimulate the cells is unknown. A second factor that supports the idea that the cells were not stimulated electrically is that not all cells responded to the stimulus, even those in the close neighborhood of a responding cell. This clearly speaks against an artifact.

These high frequency RF fields produced a response in many types of neurons in the avian central nervous system (in both cerebellum and cerebrum) and did not appear to be limited to any specialized receptor. Similar responses (long latency and ongoing higher activity after cessation of the stimulus) also were recorded to a 52 GHz carrier, 16 Hz modulated signal (Semm et al., unpubl. data). Thus, the effect does not appear to be limited to magnetic sensory cells [11], but may occur in any part of the brain. The similar responses to different frequencies point toward a common mechanism of low frequency modulation, perhaps at the cell membrane. Such a stimulus might mimic a natural mechanism involved in cell communication, producing responses from many different types of neurons. It is unlikely that the effects we observed are the result of thermal excitation caused by the RF radiation because the power densities we applied were 2–3 orders of magnitude below what is required (10 mW/cm^2) to produce heating of even 0.5 °C [2]. It is also unlikely that localized areas of the brain were heated and thermally stimulated because neurons responded only to the modulated signal and did not respond to unmodulated signals that were the same strength. Consequently, we conclude that the effects we observed are not the result of thermal agitation but at this point we cannot offer an athermal mechanism to account for the observations.

Although individual neurons in the zebra finch brain responded to the pulsed RF stimulus, we do not know whether these responses by the nervous system are manifested in the bird's behavior or its health. Bruderer and coworkers [4,5] reported no behavioral responses of birds to pulsed or continuous RF microwave signals, but their studies involved different frequencies and lower power densities of the stimulus. Thuróczy and coworkers reported neuronal responses of freely moving rats [12] similar to the responses we observed in the zebra finch. During the period of stimulation, sensitive cortical neurons of Long Evans rats showed either an increase or a decrease in the rate of spontaneous activity. The changes in firing rates were less than the changes we observed in the zebra finch: an increase of less than 2× in the rat versus 3.5× in the finch and a decrease to 0.67× in the rat versus 0.4× in the finch. Although the neuronal responses were similar between the rat and the finch, the SAR values of the RF field used with the rat were much greater than that used for the finch. Thuróczy and coworkers also observed behavioral responses by the rat to the GSM signal. In conditioning experiments, the rats' reaction times decreased during stimulation as did their learning rate (as measured by discrimination tasks).

Whether similar neuronal responses occur in other mammals, including humans, requires further investigation. Borbély and coworkers [3] reported that exposure to a RF signal similar to the one we used influenced sleep and sleep electroencephalogram in humans. Their results and the responses we recorded clearly indicate the potential for effects on the human nervous system.

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Chemical reaction in birds provides sense of direction during migratory flights

Study could help identify mechanism of magnetoreception in animals and humans

Irvine, Calif., May 12, 2004

Migrating birds stay on track because of chemical reactions in their bodies that are influenced by the Earth's magnetic field, a UC Irvine-led team of researchers has found.

The birds are sensitive even to rapidly fluctuating artificial magnetic fields. These fields had no effect on magnetic materials such as magnetite, indicating that the birds do not rely on simple chunks of magnetic material in their beaks or brains to determine direction, as experts had previously suggested.

The results are reported in the May 13 issue of *Nature*. The study is the first to reveal the mechanism underlying magnetoreception – the ability to detect fluctuations in magnetic fields – in migratory birds.

In the study, Thorsten Ritz, assistant professor of physics and astronomy, and colleagues exposed 12 European robins to artificial, oscillating magnetic fields and monitored the orientation chosen by these birds. The stimuli were specially designed to allow for responses that could differ depending on whether birds used small magnetic particles on their bodies or a magnetically sensitive photochemical reaction to detect the magnetic field.

"We found that the birds faced in the usual direction for their migration when the artificial field was parallel to the Earth's natural magnetic field, but were confused when the artificial field was applied in a different direction," said Ritz, the lead author of the paper. "Since the artificial field's oscillations were too rapid to influence magnetic materials like magnetite, it suggests that the most likely mechanism for magnetic orientation in these birds involves tiny changes to magnetically sensitive chemical reactions, possibly occurring in the eyes of the birds – we are not sure."

In the experiments, the robins could walk and flutter in

European robin

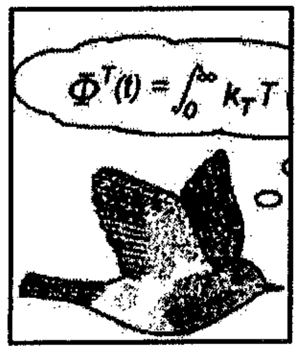

Photo credit: Thorstén Ritz

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their cages but could not fly. The birds oriented well in the Earth's magnetic field alone, but were disoriented in the presence of a broad-band (0.1-10 megahertz) and 7 megahertz oscillating field, aligned at a 24 or 48 degree angle to the Earth's magnetic field. When the same 7 megahertz oscillating field was aligned parallel to the Earth's magnetic field, the robins showed normal migratory orientation again.

"Unlike our senses involving vision, hearing, smell and touch, we do not know what receptors underlie magnetoreception," Ritz said. "Migratory birds have long been known to possess a magnetic compass that helps them find the correct direction during their migratory flights. It has remained unknown, however, how birds can detect the direction of the Earth's magnetic field.

"Now, our study points to what we need to look for a molecular substrate for certain chemical reactions. That is, we can rule out magnetic materials in birds' beaks and elsewhere as being possible candidates. Magnetite in the beaks, however, may play a role in detecting the strength but not the direction of the Earth's magnetic field."

The experiments on the birds were conducted in a six-week period in 2003 in Frankfurt, Germany, in the laboratory of Wolfgang and Roswitha Wiltschko, co-authors of the paper, who developed the behavioral experimental setup used in the study for testing magnetic orientation in birds. During migratory unrest, the birds could move in their cages. Each cage was funnel-shaped, lined with coated paper and measured approximately 1.5 feet in diameter. When the birds moved in the cages, they left scratch marks that were counted subsequently by the researchers and analyzed.

To produce artificial oscillating fields, the researchers fed high-frequency currents from a signal generator into a coil that surrounded four test cages. The coil, with a diameter of approximately two meters, could be moved to change the alignment of the oscillating field. Each bird was tested once a day during dusk for a period of approximately 75 minutes.

Besides the Wiltschkos of J. W. Goethe-Universität, Germany, Ritz was joined in the study by John B. Phillips of Virginia Tech and Peter Thalau of J. W. Goethe-Universität.

The research was funded by the Deutsche Forschungsgemeinschaft and the Fetzer Institute.

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TIMES

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From The Sunday Times
April 22, 2007

Cancer clusters at phone masts

Daniel Foggo

SEVEN clusters of cancer and other serious illnesses have been discovered around mobile phone masts, raising concerns over the technology's potential impact on health.

Studies of the sites show high incidences of cancer, brain haemorrhages and high blood pressure within a radius of 400 yards of mobile phone masts.

One of the studies, in Warwickshire, showed a cluster of 31 cancers around a single street. A quarter of the 30 staff at a special school within sight of the 90ft high mast have developed tumours since 2000, while another quarter have suffered significant health problems.

The mast is being pulled down by the mobile phone after the presentation of the evidenceoperator O2 by local protesters. While rejecting any links to ill-health, O2 admitted the decision was "clearly rare and unusual".

Phone masts have provoked protests throughout Britain with thousands of people objecting each week to planning applications. There are about 47,000 masts in the UK.

Dr John Walker, a scientist who compiled the cluster studies with the help of local campaigners in Devon, Lincolnshire, Staffordshire and the West Midlands, said he was convinced they showed a potential link between the angle of the beam of radiation emitted from the masts' antennae and illnesses discovered in local populations.

"Masts should be moved away from conurbations and schools and the power turned down," he said.

Some scientists already believe such a link exists and studies in other European countries suggest a rise in cancers close to masts. In 2005 Sir William Stewart, chairman of the Health Protection Agency, said he found four such studies to be of concern but that the health risk remained unproven.

ORIGINAL ARTICLE

Subjective symptoms, sleeping problems, and cognitive performance in subjects living near mobile phone base stations

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See end of article for authors' affiliations

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Background: The erection of mobile telephone base stations in inhabited areas has raised concerns about possible health effects caused by emitted microwaves.
Methods: In a cross-sectional study of randomly selected inhabitants living in urban and rural areas for more than one year near to 10 selected base stations, 365 subjects were investigated. Several cognitive tests were performed, and wellbeing and sleep quality were assessed. Field strength of high-frequency electromagnetic fields (HF-EMF) was measured in the bedrooms of 336 households.
Results: Total HF-EMF and exposure related to mobile telecommunication were far below recommended levels (max. 4.1 mW/m^2). Distance from antennae was 24–600 m in the rural area and 20–250 m in the urban area. Average power density was slightly higher in the rural area (0.05 mW/m^2) than in the urban area (0.02 mW/m^2). Despite the influence of confounding variables, including fear of adverse effects from exposure to HF-EMF from the base station, there was a significant relation of some symptoms to measured power density; this was highest for headaches. Perceptual speed increased, while accuracy decreased insignificantly with increasing exposure levels. There was no significant effect on sleep quality.
Conclusion: Despite very low exposure to HF-EMF, effects on wellbeing and performance cannot be ruled out, as shown by recently obtained experimental results; however, mechanisms of action at these low levels are unknown.

Hand-held cellular telephones were introduced in the early 1980s. Due to the relatively high microwave exposure for users while they are on the telephone, the potential health effects of mobile phones have been studied in recent years. However, exposure to the much lower emissions from mobile phone base stations has been neglected. There have been only two observational pilot investigations,[1-2] and one experimental study.[3]

The World Health Organisation (WHO)[4] has recently recommended investigating the effects of exposure to emissions from mobile phone base stations to address public concerns.

It has often been argued that if there are detrimental long term effects from high-frequency electromagnetic fields (HF-EMF) as transmitted by mobile phone base stations, then such effects should have been found near powerful radio and television transmitters. This argument is invalid as: (1) there are very few studies on effects from radio and TV transmitters, ecological and cluster studies on cancer,[5-10] and studies on sleep and other endpoints;[11-12] (2) the results of these studies are compatible with the assumption of a moderately elevated risk; and (3) emissions from base stations differ substantially from those of other sources of HF-EMF.

There are numerous reports from physicians that base stations are associated with a number of health symptoms in neighbours. However, these symptoms might be due to fear about negative effects. Nevertheless there is evidence that long term, low level exposure to HF-EMF may result in a number of symptoms (for example, headaches, fatigue, sleep disorders, memory impairments),[13] attributed as microwave sickness syndrome.[14]

This study investigated the relation between exposure from mobile telecommunication and other sources of HF-EMFs and the associations between exposure and symptoms.

METHODS

Selection of base stations

The study covers urban as well as rural areas in Austria. The city of Vienna was selected as the urban area while villages in Carinthia represented the rural areas. Two network providers were each asked to identify about five base stations within both regions that fulfilled the following requirements:

- The antenna must have been operating for at least two years
- There had been no protests by neighbours against the base station
- There was no other base station nearby (this could only be achieved in rural areas)
- Transmission was preferably only in the 900 MHz band.

Twenty one base stations were specified, from which 10 were selected for the study based on inspection of the local conditions (population density, other sources of exposure).

Selection of study area and participants

Data from the 10 selected antenna locations, including the antenna diagram, were provided by the network companies. In order to ensure a sufficient gradient of exposure, these data were used to define the study area around the selected base station. The investigation was carried out by trained students and a medical technical assistant in Carinthia and

Abbreviations: ANCOVA, analysis of covariance; BCCH, broadcast channel; CI, confidence interval; GSM, global system for mobile telecommunication; HF-EMF, high-frequency electromagnetic fields; MHz, megahertz; POR, prevalence odds ratio; SAR, specific (energy) absorption rate; SD, standard deviation; TDMA, time division multiple access; WHO, World Health Organisation

Table 1 Demographic characteristics of subjects by exposure category

	Exposure category (mW/m^2)			
	<0.1	0.1–0.5	>0.5	p value
Age	45 (SD 16)	40 (SD 14)	44 (SD 15)	0.390
Females	60%	58%	56%	0.829
Years of residence	19 (SD 16)	17 (SD 13)	20 (SD 16)	0.403
Hours at home	10 (SD 5)	10 (SD 4)	10 (SD 5)	0.413
Employed	56%	60%	61%	0.689
Urban residence	55%	42%	49%	0.171
Education ≥ 12 y	42%	38%	40%	0.784
Mobile phone use	75%	77%	78%	0.866

p value from Kruskal–Wallis or χ^2 test.

Vienna. Based on power calculations, the projected number was 36 subjects for each of the 10 locations.

In Vienna, households were randomly selected from telephone register entries. Subjects were contacted by telephone. If after three attempts no contact could be achieved, the next entry in the telephone list was chosen. Subjects were told that the relationship between environmental factors and health would be investigated. They had to be older than 18 years, have been living in their present house for at least one year, and been staying there for a minimum of eight hours a day on average. Refusal was slightly above 40% and mainly due to time constraints. On acceptance of participation an appointment was made for a visit. In Carinthia the procedure was different because no clear relation of address to study area could be ensured (houses are not always numbered consecutively). Therefore a random selection of houses based on the site plan was performed. Investigators contacted subjects directly in their homes. In the case of acceptance, either an appointment for the investigation was made or it was carried out immediately. Rate of refusal was somewhat lower than in the urban area (32%). On contact, gender, age, and duration of residence in their present house (eligibility criteria) were registered. Non-participants were insignificantly more frequently males (47% *v* 41%) and significantly younger (40 *v* 44 years), and had a significantly shorter time living in their present house (13 *v* 16 years).

Data collection and measurements

All investigations were done in the homes of the subjects using a laptop computer. Performance tests as well as questionnaires were presented along with instructions on the screen. Handling was so simple that after a short introduction all subjects were able to fulfil the tasks without further assistance by the investigators. The investigation consisted of the following:

- Sociodemographic data, sources of EMF exposure within the household, regular use of mobile telephones.
- Evaluation of environmental quality, subjective scaling of the impact different environmental factors could have on the health of the subjects. Among the items listed were traffic noise, particulate matter, and mobile phone base station. Assumed impact was rated on a five point scale from 0 = not at all, to 4 = very strong impact.
- Subjective scaling of symptoms (Zerssen scale).[15] Symptoms were rated on a four point scale from 0 = not at all, to 3 = strong. Symptoms of special interest were headaches, symptoms of exhaustion, and circulatory symptoms (see table 4). For analysis, ratings were dichotomised (0/1–3).
- Investigation of sleeping problems (Pittsburgh sleeping scale).[16] Problems falling asleep and staying asleep were rated by the participants on a frequency scale ranging from never to more than 3 days a week. The global index is

Table 2 Exposure categories and results of analysis of covariance for tests of cognitive performance

	Exposure category (mW/m^2)			
Test	<0.1	0.1–0.5	>0.5	p value
Memory				
Immediate memory*	6.2 (1.4)	5.6 (1.4)	5.9 (1.5)	0.166
Short term memory (1 min)†	29.1 (4.3)	29.5 (4.1)	29.3 (3.9)	0.364
Short term memory (5 min)†	33.9 (2.9)	33.1 (3.1)	34.0 (1.9)	0.761
Short term memory (15 min)†	33.4 (2.9)	33.6 (2.4)	33.7 (2.0)	0.883
d' (1 min)‡	0.87 (0.48)	0.88 (0.42)	0.86 (0.41)	0.737
d' (5 min)‡	1.54 (0.39)	1.48 (0.62)	1.53 (0.32)	0.579
d' (15 min)‡	1.56 (0.39)	1.54 (0.32)	1.62 (0.27)	0.198
ln β (1 min)§	−0.34 (0.45)	−0.19 (0.32)	−0.29 (0.30)	0.235
ln β (5 min)§	−1.09 (0.58)	−1.11 (0.72)	−1.04 (0.54)	0.605
ln β (15 min)§	−1.36 (0.53)	−1.21 (0.52)	−1.47 (0.53)	0.095
Perceptual speed				
Speed score (sec)	4.3 (0.9)	4.0 (1.1)	3.8 (1.0)	0.061
Items solved (max. 8)	4.6 (2.4)	4.1 (2.3)	4.1 (2.5)	0.147
Choice reaction task				
Reaction time (msec)	582 (217)	511 (139)	585 (244)	0.485

Results expressed as mean (SD).
p values for exposure factor are shown.
*Highest number of correctly reproduced digits.
†Number of correctly identified items (sum of correct detections (from 20) and correct rejections (from 20 distraction items)).
‡d-prime from signal detection analysis.
§Natural logarithm of detection bias beta.

computed as the sum of seven sub-scales (see table 5) with each component scored 0 to 3 (higher score indicates greater problems).

- Cognitive performance.
  - Memory tasks consisted of a short term memory test using 1–10 digit numbers that had to be reproduced immediately after presentation. The score was defined as the highest number of digits correctly reproduced. The assessment of medium term memory was based on 20 simple everyday objects in silhouette drawings presented together for 30 seconds on the screen. After 1, 5, and 15 minutes these items together with 20 distraction items (different for the three tests) were presented in random sequence, one at a time, and the subjects had to decide whether or not the picture was among those presented. Each response was followed by immediate feedback. After each test all objects were again presented for 15 seconds. The score was defined as the number of correct responses. In addition, d-prime and response bias (beta) from signal detection analysis were computed (d-prime is the normalised distance between the signal and noise answer distributions, the higher the d-prime, the less likely is confusion between target and distraction items; beta measures the bias to respond "yes" whether it is a target or distraction item).
  - The choice reaction task consisted of a random sequence of squares of three different colours (red, green, and yellow) appearing at random locations on the screen. Subjects had to react as fast as possible by pressing a specified button for each colour. The score was defined as the average correct reaction time across 25 trials.
  - Perceptual speed was tested by presenting two series of 10 letters ("meaningless words") that differed at exactly one position. Eight of these double series were presented in random sequence. Subjects had to find the differing letter under time constraints (maximum 6 seconds) and place a cursor below it. These position varied between the 3rd and 7th letters. Score was defined as the average time to achieve the correct solution. In addition, the number of items solved within the time window was computed.

After completion of the questionnaires and tests, dates were arranged for exposure measurements. Measurements of high frequency EMFs were done by a specialist from a certified centre in Vienna (TGM). A biconic field probe (PBA 10200, ARC Seibersdorf) was used connected to a spectrum analyser (FSP, Rhode & Schwarz). Measurements were performed in the bedroom (this being typically the only place in the house where people consistently spend many hours a day). As exposure may vary at this location, in addition to the sum of power densities across all mobile phone frequencies, the maximum exposure from the base station was computed based on measurements of broadcast channels. Broadcast channels (BCCH) operate all the time at maximum power with all time slots occupied. Hence multiplication of measurements of BCCH by the ratio of the sum of the power of all channels to that of the BCCH results in maximum possible exposure level, while the sum of BCCH measurements gives the minimum. The former is the result of all channels operating at maximum power with all time slots occupied, while the latter occurs if no traffic channel is active.

Distance from the antenna was calculated based on the coordinates of the measurement location and the base station. It ranged between 24 m and 600 m in rural areas and between 20 m and 250 m in urban areas. The smaller range in the latter was due to the vicinity of other base stations and the shadowing effect of high buildings.

Subjects

In total, 365 subjects were investigated (185 in Vienna and 180 in Carinthia). In some cases EMF measurements were not possible due to the absence of the inhabitants at the arranged date. Therefore, only data from 336 subjects could finally be evaluated.

Subjects were between 18 and 91 years of age (mean 44, SD 16 years). Fifty nine per cent were female. Average duration of residence in the house was 19 (SD 16) years, and subjects stayed for 10 (SD 5) hours a day in the immediate neighbourhood. Overall, six subjects occupied the place only after erection of the base station. All subjects slept normally at home.

Statistical analysis

Statistical evaluation of exposure from the base stations was done by analysis of covariance (ANCOVA) for components of the Pittsburgh Sleeping Scale and performance measurements, and by logistic regression analysis for subjective symptoms based on the following procedure. First the maximal power density estimates from base station frequencies were classified into three groups: $\leqslant 0.1$ mW/m^2 (approximately up to median), 0.1–0.5 mW/m^2 (between median and 3rd quartile), and >0.5 mW/m^2. Originally it was planned to define four exposure categories based on quartiles. However, it turned out that the level of exposure was too low for the two lowest exposure categories to be meaningfully discriminated and consequently these categories were combined. Average exposure levels were 0.04 mW/m^2, 0.23 mW/m^2, and 1.3 mW/m^2, respectively. Exposure level, area (rural *v* urban), and interaction were included as fixed factors, age, sex, regular use of a mobile telephone, and the subjective rating of negative consequences of the base station on health were used as covariables. Normality was assessed by Kolmogorov–Smirnov tests using Lilliefors p values, homogeneity of variance by Levene's tests. For all analyses the model with separate slopes was first tested. If none of the interactions with fix factors were significant at the 10% level, the model with homogenous slopes was computed. In addition, homogeneity of variance–covariance matrices of covariables and dependent variables across groups was tested by Box M tests. Unconditional logistic regression was performed using the same covariables. For all tests a p value below 0.05 was considered significant. No correction for multiple testing was applied.

RESULTS

Table 1 gives an overview of features of participants across exposure categories. Although none of the variables reached statistical significance, the somewhat higher proportion of subjects from the urban area in the lowest exposure category should be noted.

Exposure to high frequency EMFs was generally low and ranged from 0.0002 to 1.4 mW/m^2 for all frequencies between 80 MHz and 2 GHz; the greater portion of that exposure was from mobile telecommunications (geometric mean 73%), which was between 0.00001 and 1.4 mW/m^2. Maximum levels were between 0.00002 and 4.1 mW/m^2. Overall 5% of the estimated maximum exposure levels were above 1 mW/m^2. Average exposure levels were slightly higher in the rural area (0.05*/7.6 mW/m^2) than in the urban area (0.02*/7.1 mW/m^2).

Most subjects expressed no strong concerns about adverse health effects of the base station. In the urban and rural test areas, 65% and 61% respectively stated no concerns at all.

Table 3 Detailed results of analysis of covariance for speed score of perceptual speed as a dependent variable

Source of variation		df	MSQ	F value	p value
Covariates	Combined	4	54.980	19.721	0.000
	Concerns about base station	1	2.618	0.939	0.333
	Age	1	216.469	77.648	0.000
	Sex	1	0.028	0.010	0.920
	Use of mobile phone	1	0.803	0.288	0.592
Main effects	Combined	3	28.562	10.245	0.000
	Area (rural/urban)	1	69.948	25.090	0.000
	GSM exposure	2	7.869	2.823	0.061
Interaction		2	0.036	0.001	0.999

Factors and covariables are shown in the column "source of variation".
df, degrees of freedom; MSQ, mean sum of squares.

Table 2 gives an overview of results from ANCOVA on the different tests of cognitive performance for the exposure factor only; table 3 shows the full results for the test of perceptual speed. For perceptual speed a tendency for faster reaction in the higher exposure category was found. Omitting the three insignificant covariates from analysis resulted in a significant ($p = 0.009$) main effect for exposure. Logistic regression with the median chosen as a cut-off point was statistically significant. The estimated risk of a value below the median speed score relative to the lowest exposure category was 0.73 (95% CI 0.33 to 1.58) for the second and 0.42 (95% CI 0.18 to 0.98) for the third exposure categories. Accuracy of perceptual speed indicated by number of correct reactions showed the opposite effect, although not

Table 4 Relative risk estimates of subjective symptoms of primary interest for categories of exposure to microwaves from base stations in the bedroom against lowest exposure category

Symptom	Exposure category (mW/m²)	% with symptom	Relative risk*	95% CI	p value
Headaches	≤0.1†	61	1.00		0.017
	0.1–0.5	66	1.36	0.62–2.99	
	>0.5	79	3.06	1.22–7.67	
Vertigo	≤0.1†	17	1.00		0.306
	0.1–0.5	27	1.27	0.50–3.22	
	>0.5	32	1.54	0.68–3.50	
Palpitations	≤0.1†	26	1.00		0.444
	0.1–0.5	32	1.06	0.45–2.47	
	>0.5	38	1.37	0.61–3.11	
Tremor	≤0.1†	12	1.00		0.062
	0.1–0.5	9	0.68	0.19–2.41	
	>0.5	26	2.37	0.96–5.87	
Hot flushes	≤0.1†	32	1.00		0.739
	0.1–0.5	26	0.90	0.39–2.09	
	>0.5	26	0.87	0.37–2.01	
Sweating	≤0.1†	34	1.00		0.455
	0.1–0.5	38	1.05	0.47–2.32	
	>0.5	40	1.35	0.61–2.97	
Cold hands or feet	≤0.1†	40	1.00		0.019
	0.1–0.5	46	1.03	0.40–2.63	
	>0.5	62	2.57	1.16–5.67	
Loss of appetite	≤0.1†	13	1.00		0.069
	0.1–0.5	17	1.23	0.42–3.57	
	>0.5	24	2.40	0.93–6.18	
Loss of energy	≤0.1†	63	1.00		0.886
	0.1–0.5	63	1.32	0.61–2.84	
	>0.5	58	1.06	0.49–2.27	
Exhaustion	≤0.1†	44	1.00		0.098
	0.1–0.5	41	0.77	0.30–2.02	
	>0.5	51	2.07	0.87–4.89	
Tiredness	≤0.1†	64	1.00		0.258
	0.1–0.5	89	1.97	0.64–6.10	
	>0.5	88	1.92	0.62–5.96	
Difficulties to concentrate	≤0.1†	60	1.00		0.035
	0.1–0.5	64	1.32	0.61–2.86	
	>0.5	76	2.55	1.07–6.08	
Feeling strained	≤0.1†	44	1.00		0.450
	0.1–0.5	51	1.67	0.76–3.65	
	>0.5	40	0.74	0.33–1.63	
Urge for sleep	≤0.1†	47	1.00		0.630
	0.1–0.5	54	1.21	0.56–2.61	
	>0.5	51	1.17	0.53–2.54	

p values for exposure factor are shown.
*Adjusted for age, sex, region, regular use of mobile telephone, and fear of adverse effects of the base station.
†Reference category.

Table 5 Results of analysis of covariance for components and global score of the Pittsburgh Sleep Quality Index and logistic regression for "poor sleepers" (global score >5)

Component	Exposure category (mW/m²)			p value
	<0.1	0.1–0.5	>0.5	
Subjective sleep quality	0.71 (0.79)	0.60 (0.77)	1.00 (0.89)	0.240
Sleep latency	0.76 (0.93)	0.74 (0.95)	0.94 (0.98)	0.295
Sleep duration	1.06 (0.98)	1.14 (1.03)	1.21 (1.09)	0.504
Habitual sleep efficiency	0.54 (0.92)	0.70 (0.98)	0.74 (1.15)	0.061
Sleep disturbances	0.92 (0.58)	0.91 (0.66)	0.91 (0.62)	0.338
Daytime dysfunction	0.66 (0.75)	0.54 (0.70)	0.82 (0.90)	0.099
Sleep medication	0.10 (0.46)	0.17 (0.71)	0.21 (0.73)	0.216
Global score	4.74 (3.52)	4.78 (3.86)	5.87 (4.21)	0.282
Poor sleepers (%)	35%	31%	41%	0.225

Results expressed as mean (SD).
p values for exposure factor are shown.

to a significant extent. Hence there is some speed–accuracy trade-off.

For subjective symptoms of primary interest, effects of exposure from the base station are shown in table 4. Many symptoms were more frequent at higher exposure levels; headaches, cold hands or feet, and difficulties in concentrating, and to a lesser degree, tremor, loss of appetite, and feelings of exhaustion showed increased prevalence after correction for confounding factors.

Results for sleep quality are shown in table 5. Two subscales (sleep efficiency and daytime dysfunction) showed indications of poorer sleep at higher exposure categories. A highly significant effect of concerns about negative health implications of the base station was found for overall sleep quality (global score), with poorer quality in those concerned. As expected, age also had a significant influence. Without considering the influence of the subjects' concerns about the base station, the effect of exposure would have been statistically significant. Logistic regression analysis with the median score as a cut-off point showed no pronounced effect of exposure ($p = 0.131$).

DISCUSSION

Mobile phone base stations easily comply with current guidelines (for example, ICNIRP (International Commission on Non-Ionizing Radiation Protection) guidelines).[17] Our measurements show that exposure of the public in the vicinity of base stations is indeed low. However, considering all HF-EMF exposures above 80 MHz, mobile telecommunication is responsible for an average of 73% of these exposures. This is consistent with representative measurements in Sweden[18] and the UK.[19]

The present study was conducted to provide answers to intriguing methodological problems of the epidemiological investigation of base stations.

How is it possible to attribute effects to a specific source of HF-EMF? In study areas, exposure from other sources of HF-EMFs was from distant transmitters and therefore more or less constant. Effects from these exposures will therefore not confound the effects of base stations. As study areas were selected to guarantee a gradient of exposures from base stations, the only relevant contribution to the variance of HF-EMF exposure was from base stations (93% of variance).

Another problem is the time variation of exposure, depending on the number of connected calls (due to the TDMA (time division multiple access) mode of the GSM system). Of course the best approach would be a long term measurement of exposure, or to use personal "dosimeters". However, there are no such dosimeters available and long term measurements are not feasible due to economic restrictions as well as problems of compliance. A possible solution is to conduct a short term measurement at a location where subjects are assumed to spend considerable periods of time (we chose the bedroom), analyse the spectrum of exposure, and select the broadcast channels that are operating at constant maximum power. Based on these measurements a range of exposures can be computed. We analysed data based on broad categories so that this categorisation leads to almost equal allocation whether "average", minimum, or maximum exposure estimation is used. A broad categorisation was used because of other sources of variance of exposure (like movements of subjects) that cannot be accounted for.

A further problem is the dynamic development of telecommunication networks. For the present study, we selected base stations emitting with unchanged features for

Table 6 Results of analysis of covariance (ANCOVA) for global score of the Pittsburgh Sleep Quality Index as dependent variable

Source of variation		df	MSQ	F value	p value
Covariates	Combined	4	323.407	11.770	0.000
	Concerns about base station	1	482.088	17.545	0.000
	Age	1	661.076	24.059	0.000
	Sex	1	87.286	3.177	0.076
	Use of mobile phone	1	63.176	2.299	0.130
Main effects	Combined	3	42.571	1.549	0.202
	Area (rural/urban)	1	57.795	2.103	0.148
	GSM Exposure	2	34.959	1.272	0.282
Interaction		2	58.404	2.126	0.121

Factors and covariables are shown in the column "source of variation".
df, degrees of freedom; MSQ, mean sum of squares.

Main messages

- Exposure from mobile phone base stations is orders of magnitude below current guideline levels.
- Self-reported symptoms like headache and difficulties in concentrating show an association with microwave exposure from base stations, not attributable to subjects' fear of health effects from these sources.
- Other symptoms, like sleeping problems, seem to be more due to fear of adverse health effects than actual exposure.

Policy implications

- Despite very low emissions from mobile phone base stations, more research concerning the effects of radiofrequency radiation from base stations is indicated.
- As a precautionary measure, siting of base stations should be such as to minimise exposure of neighbours.

at least two years. Furthermore, it was important that no other base station was nearby (which, however, could only be achieved in rural areas).

Because of the much higher exposure during telephoning compared to exposure from base stations, it is hardly conceivable that such small additional exposure could have an effect. However, these exposures have fundamentally different features. Exposure from the base station will be at low, but more or less constant levels for many hours a day, especially during the night. Comparing these levels is inappropriate if long term effects actually exist. If, for example, a subject is using a GSM mobile with a specific energy absorption rate (SAR) of 0.04 W/kg[20] for 10 minutes, this would be roughly equivalent to a 15 day exposure from a base station at an exposure level of 1 mW/m^2 if the principle of time–dose reciprocity is valid. However, it is not known whether this principle holds for exposure to HF-EMFs.

There is no a priori argument why the much lower levels from base stations should have no effect in the presence of widespread use of mobile telephones. Possible confounding by using a mobile has been considered in this study.

Generally, ratings were higher for most symptoms in subjects expressing concerns about health effects from the base station. Subjects who experience health problems might search for an explanation in their environment and blame the base station; another explanation would be that subjects with concerns are more anxious and also tend to give a more negative view of their body functions, or that some people generally give quite negative answers. Irrespective of these explanations there seem to be effects of exposure that occur independently of the fear of the subjects about the base station affecting their health. This is the case for headaches, cold hands or feet, and difficulties in concentrating, for example. These effects were robust with respect to additional potential confounders (for example, for headaches, inclusion of an indicator of socioeconomic status—years of education and type of occupation—slightly increased the risk estimator for exposure and decreased the p value from 0.017 to 0.016; inclusion of years of living in the present home and overall rating of environmental quality slightly increased the p value to 0.019; inclusion of hours staying at home did not change effect estimates at all). Interestingly these symptoms as well as some others that tended to be increased at higher exposure levels belong to those attributed to the microwave sickness syndrome. However, no clear relationship has been found for sleeping problems that are often mentioned in the public debate. The effect on sleep is dominated by concerns of the subjects of negative health effects of the base station. Many factors are known to influence sleep quality. Only a few could be considered in this study. Since some aspects of sleep quality, like sleep efficiency, showed a tendency for being affected by exposure, future studies should attempt to eliminate additional confounders.

Concerning symptom reporting there are a number of personality factors for which an association has been established. Among these are state anxiety, depression, and negative affectivity. The main question concerning this range of factors is whether they might act as confounders. In discussions of the microwave sickness syndrome, depression has also been mentioned among the possible effects of exposure; confounding is therefore conceivable. Sleep quality, unspecific symptoms, depression, affectivity, and other personality characteristics are connected with each other in a network of relationships such that a clear understanding of the possible long term effects of exposure may only be determined by longitudinal studies.

No influence of the subjects' fear about negative effects of the base station was found for cognitive performance. There was a small but significant reduction of reaction time for perceptional speed at increased exposure levels. It is interesting to note that such facilitating effects have also been reported during short term experimental exposures[20 22] and a study in teenagers using mobile phones.[21] On the other hand, a study[12] in children chronically exposed to emissions from a radio tower reported increased reaction times and reduced performance in cognitive tasks. We found a reduction of reaction time in adults, but an insignificant decrease of accuracy. Recognition in the medium term memory task showed a reasonable and increasing differentiation between target and distraction items and a decreasing response bias over repeated tests, but there was no indication of an influence of exposure from the base station. Furthermore, cognitive performance varies with factors that have not been controlled or considered in this study. Indices of socio-economic status, however, were tested and did not modify effect size of base station exposure.

The results of this study indicate that effects of very low but long lasting exposures to emissions from mobile telephone base stations on wellbeing and health cannot be ruled out. Whether the observed association with subjective symptoms after prolonged exposure leads to manifest illness remains to be studied.

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Survey Study of People Living in the Vicinity of Cellular Phone Base Stations

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ABSTRACT

A survey study was conducted, using a questionnaire, on 530 people (270 men, 260 women) living or not in proximity to cellular phone base stations. Eighteen different symptoms (Non Specific Health Symptoms–NSHS), described as radiofrequency sickness, were studied by means of the chi-square test with Yates correction. The results that were obtained underline that certain complaints are experienced only in the immediate vicinity of base stations (up to 10 m for nausea, loss of appetite, visual disturbances), and others at greater distances from base stations (up to 100 m for irritability, depressive tendencies, lowering of libido, and up to 200 m for headaches, sleep disturbances, feeling of discomfort). In the 200 m to 300 m zone, only the complaint of fatigue is experienced significantly more often when compared with subjects residing at more than 300 m or not exposed (reference group). For seven of the studied symptoms and for the distance up to 300 m, the frequency of reported complaints is significantly higher ($P < 0.05$) for women in comparison with men.

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Significant differences are also observed in relation to the ages of subjects, and for the location of subjects in relation to the antennas and to other electromagnetic factors.

Key Words: Cellular phone base stations; Bio-effects.

INTRODUCTION

Chronic exposure to ultra-high-frequency electromagnetic fields or microwaves brings on bioeffects in man such as headaches, fatigue, sleep, and memory disturbances (Bielski, 1994; Santini, 1999). These biological effects, associated with others (skin problems, nausea, irritability) constitute what is known as "Non Specific Health Symptoms" (NSHS) that characterize radiofrequency sickness (Johson Liakouris, 1998). Cellular mobile phone technology uses microwaves (frequencies of 900 or 1800 MHz in France) pulsed with extremely low frequencies (frequencies <300 Hertz) (Linde and Mild, 1997). However many of the biological effects resulting from mobile phone use are relatively well-known and bring to mind those described in radiofrequency sickness (Mild et al., 1998; Santini et al., 2002).

We are reporting here the results concerning 530 people living in France, in the neighborhood or not, of cellular phone base stations, in relation to their exposure conditions to antennas, their sex, and their age.

MATERIALS AND METHODS

Questionnaire Used

A questionnaire similar to that developed for the study on mobile phone users (Santini et al., 2002) was sent to people wishing to participate in the study. Subjects were enrolled through information given by press, radio, and web sites, about the existence of a study on people living near cellular phone base stations. The questionnaire was filled out by subjects without the presence of a person in charge of the study and was returned (generally by mail) to a person responsible for the study.

General questions pertained to age, sex, estimated distances from base stations (less than 10 m, 10–50 m, 50–100 m, 100–200 m, 200–300 m, more than 300 m) and their location in relation to the antennas (facing, beside, behind, beneath in the case of antennas placed on rooftops). The exposure conditions of subjects were also defined by the length of time living in the neighborhood of base stations (less than 1 year, 1–2 years, 2–5 years, more than 5 years).

Participants were asked to indicate the presence or not of electrical transformers (at less than 10 m), high or very high tension electric power lines (at less than 100 m) and radio and television transmitters (at less than 4 km). The questionnaire sought information on computer use (more than 2 hours per day) and cellular telephone use (more than 20 minutes per day).

The level of complaints for the studied symptoms was expressed by the study participants using a scale of: 0 = never, 1 = sometimes, 2 = often, and 3 = very often. Of 570 questionnaires received, 40 were not used because of lack of information on the distance from the base stations or on the level of the complaints experienced. Among the 530 questionnaires studied, 270 came from men (45 years ± 20) and 260 from women (47 years ± 19). Eighteen symptoms referenced in the NSHS were found in the questionnaire; one of which, premature menopause, concerned only women.

Analysis of Results

The results obtained, concerning the frequency of the complaints experienced in relation to responses with 0 = never, were analyzed by the chi-square test with Yates correction (Dabis et al., 1992) by means of a software program (STATITCF, 1987, France). Results were compared with the frequency of complaints of the reference group (subject exposed at >300 m or, living in the vicinity of nonoperating base stations) for incidences of distance and age. The comparisons were done with the frequency of complaints expressed by subjects exposed up to 300 m for length of exposure (comparison to <1 year), for location of subjects (comparison of locations among themselves) and for sex. A $P < 0.05$ was considered significant.

We are presenting here the results tallied with: (1) the influence of subject's exposure conditions to base stations (distance, length of exposure, location in relation to the antennas other electromagnetic factors), and (2) the influence of sex and age of subjects.

RESULTS

Influence of Exposure Conditions

Distance

The 530 study subjects were distributed in the following manner: 19.6% were less than 10 m from cellular phone base station antennas, 26.2% between 10 and 50 m, 13.8% between 50 and 100 m, 9.6% between 100 and 200 m, 10.1% between 200 and 300 m, and 20.7% were at more than 300 m or not exposed; these last subjects were chosen as the reference group.

In comparison with the reference group, the complaints are experienced in a significantly higher way by the subjects located in the distance zones of <10 m to 300m from base stations. Certain symptoms are experienced significantly more often ($P < 0.05$) only in the immediate vicinity of base stations (up to 10 m) and not beyond that: Nausea, loss of appetite, visual disturbances, and difficulty in moving. Significant differences ($P < 0.05$) are observed up to 100 m from base stations for symptoms such as: Irritability, depressive tendencies, difficulties in concentration, loss of memory, dizziness, and lowering of libido. In the zone 100 m to 200 m from base stations, the symptoms of headaches, sleep disruption, feelings of discomfort, and skin problems are again experienced significantly more often ($P < 0.05$) in comparison with the reference group. Beyond 200 m, only the symptom of fatigue is reported at a significantly high frequency ($P < 0.05$) (Table 1). By contrast, no significant effect is demonstrated in relation to distance for the symptom of premature menopause. A significant lowering of libido was reported by subjects living at the distances of less than 10 m, 10–50 m, and 50–100 m from base stations.

Table 1. Influence of distances from cellular phone base stations on the percentages of complaints

	Distances from base stations in meters (m)											
	< 10 m		10–50 m		50–100 m		100–200 m		200–300 m		> 300 m	
Symptoms	2	3	2	3	2	3	2	3	2	3	2	3
Fatigue	76*	72*	63.5*	50.9*	60.6	56.6*	64.2	41.1	66.6*	43.7	40.7	27.2
Irritability	32.8	23.2*	41.7*	25.7*	47.2*	44.1*	25.8	4.1	25	9	18	3.3
Headaches	51*	47.8*	40*	26.1*	40.6*	36.7*	60.7*	31.2*	19.3	0	15.6	1.8
Nausea	14.5*	6.9	8.4	3	5.7	3.8	2.4	4,6	0	2.3	2,1	1.1
Loss of appetite	20.4*	8.3	8	5.5	5	5	6.9	0	4.2	0	3.3	3.3
Sleep disturbances	41.3*	57.1*	41.4*	57.5*	46.9*	58.5*	45.8*	50*	33.3	35.5	13.8	21.1
Depressive tendencies	16,9	26.8*	21.6	19.7*	11.6	24*	16.2	3.1	13.6	2.5	10.3	3.7
Feeling of discomfort	28*	45.4*	25.2*	18.9	30.6*	12.8	15.7*	0	9.7	5.1	2.4	8.1
Difficulties in concentration	39.3	28.8*	37.5	16.6	34.2	26.4*	25	12.5	43.3	5.5	26.7	7.1
Memory loss	27.8	25.4*	29.4	26.6*	37.1*	29*	25	15.6	17.2	11.1	17.9	5.8
Skin problems	18.1*	17.1*	6.6	10.8	11.1*	11.1	13.9*	7.5	8.7	0	1.2	4.6
Visual disturbances	14.5	24.3*	23	13.5	22	7.1	2.5	4.9	15	2.8	13.6	4.1
Hearing disturbances	33.3*	17.4	17.7*	12	8.3	15.5	7.7	7.7	11.6	9.5	5.6	8.7
Dizziness	10	12.5*	17.3*	7,5*	9.6	9.6*	12.2	2.7	7.7	5.2	6.2	0
Movement difficulties	5.6	7.7*	8.2	1.7	3	3	0	0	2	0	2.9	1
Cardiovascular problems	10.1*	13*	15.3*	9.6	12.3*	7.4	8.7	0	8.5	6.5	1	3

for 16 non Specific Health Symptoms experienced by 530 people (270 men + 260 women).

* = $P < 0.05$ in comparison to the reference group (> 300 m) for the responses 2 = often and 3 = very often.

Length of Exposure

There is no significant difference in the frequency of symptoms expressed by subjects living up to 300 m from cellular phone base station, according to the length of time (< 1 year to more than 5 years) they have lived in the neighborhood of base stations.

Location of Subjects

The location of subjects in relation to the antennas (facing, beside, behind, beneath) taken alone has little impact on the frequency of symptoms reported. When comparisons are made in relation to the different distance zones, significant increases of complaints ($P < 0.05$) are observed for some distances and for some symptoms in the facing position: visual disturbances for distance < 10 m as compared with beneath, fatigue for distance 10 to 50 m as compared with beneath, headache for distance 10 to 50 m as compared with beside, memory loss for distance 50 to 100 m as compared with beside. When comparisons are made for all subjects exposed at a distance of up to 300 m from base stations, it is only observed a significant increase in headaches ($P < 0.05$) for subjects in the beneath position as compared with subjects in the facing position.

Table 2. Influence of sex on the percentages of complaints

Symptoms	Men (%)	Women (%)
Fatigue	41.4	57.5
Irritability	17.9	28.3
Headaches (3)	14.4	45.6*
Nausea (3)	0	5.9*
Loss of appetite (3)	1.9	8*
Sleep disturbances (3)	45.4	61*
Depressive tendencies (3)	9.8	26.7*
Feeling of discomfort (3)	15	25.4*
Difficulties in concentration	18.4	21.6
Memory loss	18	27.7
Skin problems	8	13.1
Visual disturbances (2)	12.2	22*
Hearing disturbances	9.6	19
Dizziness	6	9.8
Movement difficulties	3.3	2.7
Cardiovascular problems	8.3	8.8
Lowering of libido	18	12

for 17 Non Specific Health Symptoms reported by 420 people (205 men vs. 215 women) living in the vicinity of cellular phone base stations (all distances from < 10 m to $\leqslant$ 300 m).

* = $P < 0.05$ for level of complaints in parenthesis, 2 = often and 3 = very often.

Exposure to Other Electromagnetic Factors

The presence of factors such as an electrical transformer, very high tension electric power lines, radio-television transmitters, the use of computers, or cellular phones has little influence on the frequency of symptoms reported by subjects living at a distance of up to 300 m from base stations. However, a significant decrease of sleep disturbance for cellular phone users, and significant increases of discomfort and dizziness with the presence of an electrical transformer, and of difficulties in concentration with the presence of a radio-television transmitter, are observed in comparison with subjects living at a distance of up to 300 m, but not exposed to those factors.

Table 3. Influence of age on the percentages of complaints

	≤20 years		21–40 years		41–60 years		>60 years	
	Distances of subjects from antennas (in meters)							
Symptoms	≤300	>300	≤300	>300	≤300	>300	≤300	>300
Fatigue	56.7	62.5	82.4*	25	81.4*	57.8	73.3*	40
Irritability	16.2	11.1	46.2	18.2	50.5	35.3	52.1*	21
Headaches	42.4	26.3	57.6*	18.2	52*	13,3	49.5*	10
Nausea	2	0	12.9	0	9.9	0	15.6	15.7
Loss of appetite	13.3	8.8	12.7	0	11.8	0	15.9	15
Sleep disturbances	26.1	14.8	53*	12,5	73.9	52.6	68.5*	44.4
Depressive tendencies	10.2	5.7	14	5.8	36	20	41.7	27.7
Feeling of discomfort	4.4	2.9	26.3	6	41.6	16.6	45*	19
Difficulties in concentration	30.3	40	42.1	18.7	45.8	36.8	53.3*	20
Memory loss	7.5	8	21.8	6.6	43	40	64	36.8
Skin problems	16.6	9.3	24.2	6.6	18.3	0	20.4	5.2
Visual disturbances	16.3	12.5	14.7	12.5	26.6	26.3	36.8	17.6
Hearing disturbances	9.4	5.1	15.4	0	29.8	21.7	43.8	31.5
Dizziness	6.2	5.2	3.2	6.6	15.4	4.5	39.3*	9.5
Movement difficulties	0	2.3	0	0	3.5	4	21.4	10.5
Cardiovascular problems	0	2.3	5.1	0	19.2*	0	36.4	15

for 16 Non Specific Health Symptoms experienced by 530 people (270 men + 260 women) in relation to their distances from cellular phone base stations (≤300 m vs. >300 m [reference group]).

* = $P < 0.05$ for levels of complaints 2+3 pooled.

Influence of Sex and Age

Sex

In terms of the different distance zones, two complaints were experienced significantly more often for women ($P < 0.05$): nausea in the zone of less than 10 m, headaches in the zones of 10–50 m, 50–100 m, 100–200 m, and 200–300 m. Men complain significantly more often ($P < 0.05$) than women about lowering of libido in the zone of 50 to 100 m from cellular phone base stations.

When the men/women comparison is made for all subjects exposed at a distance up to 300 m, seven symptoms (i.e., headaches, nausea, loss of appetite, sleep disturbances, depressive tendencies, feeling of discomfort, and visual disturbances) are experienced significantly more often in women ($P < 0.05$) (Table 2). On the contrary, for the subjects of the reference group, there appears to be no significant difference related to sex in the frequency of complaints reported for the different symptoms.

Age

Significant differences are observed in relation to the age of the subjects (from 21 to >60 years) for symptoms such as fatigue, irritability, headaches, sleep disturbances, feeling of discomfort, dizziness, cardiovascular problems when comparisons are made between subjects living up to 300 m vs. subjects of the reference group. For subjects younger than 20 years of age, there is no significant difference in the frequency of symptoms between subjects living at up to 300 m vs. subjects of the reference group (Table 3).

DISCUSSION

This study gives evidence of the fact that NSHS are reported by people at distances up to 200 m to 300 m from cellular phone base stations. The significant increase in the frequency of complaints in relation to the reference group (people exposed at >300 m or not exposed) goes in the direction of the observation found in an Australian governmental report, which had signaled that at 200 m from a base station, some people exposed in their homes are complaining of chronic fatigue and sleep disturbances (Australian Report, 1996). Our results agree with those of a Spanish preliminary study on people living in the vicinity of cellular phone base stations, where symptoms as irritability, headaches, nausea, and sleep disturbances are experienced in a significantly higher way by the subjects located at a distance up to 150 m vs. subjects at a distance >250 m (Gomez-Perretta Cl, personnal communication, 2002).

The number of reported symptoms is higher close to base stations, and that number decreases with increased distance from them, in relation to the fact that some symptoms such as nausea, loss of appetite, visual disturbances, and difficulties in movement are no longer experienced in a significant way beyond 10 m.

Symptoms such as fatigue, headaches, and sleep disturbances, which are experienced significantly at considerable distances from base stations, exhibit no notable diminishment in the percentages of complaints experienced with increased distance. But the measurements of electromagnetic fields in the neighborhood of cellular phone base stations show a reduction in strength over distance (Petersen and Testagrosa, 1992; Santini, 1999). One could expect that human sensitivity to electromagnetic waves is such that increased distance from cellular phone base stations has no significant effect on certain NSHS symptoms up to a distance of 200 to 300 m (difference in receptors sensibility to microwaves?). It is also possible that the measurements of electromagnetic fields found around base stations may not be the true representation of populations exposure. In fact, different parameters are likely to interfere to modify the measurements and in particular fluctuations in emission strengths relating to the number of calls handled by base stations, the reflection of electromagnetic waves, etc. (Santini et al., 2000).

No significant decrease was observed in the frequency of symptoms in relation to the length of time living in the neighborhood of base stations (from <1 year to >5 years). This result shows that there is no acclimation of subjects to microwave bioeffects with duration of exposure.

This study shows that for some distances and for some symptoms, the facing location is the worst position, especially for distances of <100 m from cellular phone base stations. This result can be related to the fact that antennas emit microwave at a higher level in front than in other directions (Petersen and Testagrosa, 1992).

The results obtained demonstrate the greater sensitivity of women for 7 of the studied NSHS. One earlier study related to cellular phones users demonstrated an increase in women's sensitivity for the symptom of sleep disturbances (Santini et al., 2002). This sex-related difference is parallel to the particular sensitivity of women to electromagnetic fields (Loomis et al., 1994; Santini, 1998). The results obtained in this study also show the existence of a greater sensibility for some NSHS symptoms, in relation to age, in subjects older than 20 years. This sensibility is particularly high in subjects older than 60 years. This last results agrees with the greater sensibility of the elderly to radiofrequencies (Tell and Harem, 1979).

CONCLUSION

From these results and in applying the precautionary principle, it is advisable that cellular phone base stations should not be sited closer than 300 m to populations and most significantly because exposed people can have different sensitivities related particularly to their sex and their age. The facing position appears to be the worst one for distances from cellular phone base stations <100 m.

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