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Short communication

Anthropogenic radiofrequency electromagnetic fields as an emerging threat to wildlife orientation

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HIGHLIGHTS

- The growth of wireless telecommunication technologies causes increased electrosmog.
- Radio frequency fields in the MHz range disrupt insect and bird orientation.
- Radio frequency noise interferes with the primary process of magnetoreception.
- Existing guidelines do not adequately protect wildlife.
- Further research in this area is urgent.

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ABSTRACT

The rate of scientific activity regarding the effects of anthropogenic electromagnetic radiation in the radiofrequency (RF) range on animals and plants has been small despite the fact that this topic is relevant to the fields of experimental biology, ecology and conservation due to its remarkable expansion over the past 20 years. Current evidence indicates that exposure at levels that are found in the environment (in urban areas and near base stations) may particularly alter the receptor organs to orient in the magnetic field of the earth. These results could have important implications for migratory birds and insects, especially in urban areas, but could also apply to birds and insects in natural and protected areas where there are powerful base station emitters of radiofrequencies. Therefore, more research on the effects of electromagnetic radiation in nature is needed to investigate this emerging threat.

Different animal groups are sensitive to low frequency electromagnetic fields, and many species with receptor organs are provided with important orientation cues from natural electric fields (Kalmijn, 1988). Animals can use the direction of the magnetic field as a compass and the intensity of the magnetic field as a component of the navigational map, with light-dependent reactions in specialised photo-pigments and reactions involving small crystals of magnetite, using one of these systems, or both simultaneously, depending on the animal groups (Kirschvink et al., 2001; Johnsen and Lohmann, 2005; Wiltschko et al., 2007; Hsu et al., 2007; Ritz et al., 2009; Wajnberg et al., 2010).

Some insects, like bumblebees (*Bombus terrestris*), can interact with floral electric fields and electric field sensing constitutes a potentially important sensory modality. The perception of weak electric fields by bees in nature, which should be considered alongside vision and olfaction, may have an adaptive value (Clarke et al., 2013). An applied static magnetic field affects circadian rhythms, magnetosensitivity and orientation of insects through cryptochromes, and a prolonged weakening of the geomagnetic field affects the immune system of rats (Roman and Tombarkiewicz, 2009; Yoshii et al., 2009).

In the radiofrequency range, the rapid development and increased use of wireless telecommunication technologies led to a substantial change in the radio-frequency electromagnetic field (RF-EMF) exposure (Levitt and Lai, 2010). This increased exposure was most consistently observed in outdoor areas due to emissions from radio and mobile phone base stations (Urbinello et al., 2014). Current evidence indicates that exposure at levels found in the environment (in urban areas and near base stations), may particularly alter the receptor organs to orient in the magnetic field of the earth, although the species conservation implications are unknown. Radio frequency fields in the MHz range disrupt birds' orientation interfering directly with the primary processes of magnetoreception and therefore disable the avian compass as long as

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they are present (Wiltschko et al., 2014). Ritz et al. (2004 & 2009) reported the sensitivity for orientation of European robins (*Erithacus rubecula*) to radiofrequency magnetic fields. The orientation of migratory birds is disrupted when very weak high-frequency fields (broadband field of 0.1–10 MHz of 85 nT or a 1.315 MHz field of 480 nT) are added to the static geomagnetic field of 46.000 nT (Thalau et al., 2006). It was convincingly demonstrated that robins are unable to use their magnetic compass in the presence of urban electromagnetic radiofrequency noise in the frequency range of 2 kHz–5 MHz (Engels et al., 2014). Therefore, electrosmog scrambles birds' magnetic sense and this finding could inform policies written to protect the habitats of endangered species.

As with birds, radio frequency magnetic fields disrupt magnetoreception in insects. The geomagnetic field reception in American cockroach is sensitive to weak radio frequency field causing a disruptive effect (Vacha et al., 2009), so these authors suggest that electromagnetic smog will have to be taken more seriously in animal magnetoreception experiments. In an experimentally-generated electromagnetic field of about 1 V/m with a realistic (and even lower) power intensity similar to those surrounding communication masts, the results and observations suggest that GSM (Global System for Mobile communications) 900 MHz radiation might have a severe impact on the nerve cells of exposed ants, especially affecting the visual and olfactory memory, causing the loss of their ability to use visual cues and suggesting that electromagnetic radiation may have an impact on the orientation behaviour and navigation of animals that use magnetic fields to find their way (Cammaerts et al., 2012, 2014). Honeybees are sensitive to pulsed electromagnetic fields generated by mobile phones and observable changes in the bee behaviour could be one explanation for the loss of colonies (Favre, 2011). Magnetoreception system in Monarch butterfly orientation (Guerra et al., 2014) may be also suffering interference with anthropogenic radio frequency magnetic fields and this, together with other factors (Brower et al., 2012), may be a cause of their population decline.

Electromagnetic fields act via activation of voltage-gated calcium channels (Pall, 2013). Changes in the size of the magnetic granules upon applying additional magnetic field to the cells of *Apis mellifera* were observed, and this size fluctuation triggered the increase of calcium intracellular (Hsu et al., 2007). Therefore, we may hypothesise that some of the disruptive effects of radio frequency fields on the orientation of animals may be related to the interference with calcium channels.

An aversive effect on bats has been found in habitats exposed to radiofrequency radiation (1–4 GHz) when compared with matched sites where no such radiation can be detected (Nicholls and Racey, 2009). Cattle exposed to radiofrequency emissions (900 MHz) from nearby base stations may suffer changes in the redox proteins and enzyme activities. It was also found that some are sensitive to radiation, while others are not (Hässig et al., 2014).

Exposure to low intensity radiation can have a profound effect on biological processes (Bolen, 1994). Although there is a good degree of evidence on the injurious effects of radiofrequency electromagnetic fields on the immune system, pineal gland, circadian rhythm, oxidative stress and teratogenicity, these topics remain controversial (Lerchl et al., 2008; Takahashi et al., 2009; Jin et al., 2012; Qin et al., 2012; Bilgici et al., 2013; Tsybulin et al., 2013; Yakymenko et al., 2014; Cao et al., 2015). Conversely, there is a scientific agreement regarding harmful effects of radio frequency radiation on human reproduction (Adams et al., 2014). Low-voltage electricity current-generated electromagnetic field can produce a significantly negative effect on the breeding success of birds (*Ciconia ciconia*) nesting directly on electricity lines (Vaitkuvienė and Dagys, 2014) and these same results have been found in nests exposed to radiofrequency radiation near phone masts (Balmori, 2005).

The health risk of electromagnetic fields to aquatic organisms needs to be addressed (Lee and Yang, 2014). The potential interactions between diadromous fishes of conservation importance and the electromagnetic fields and subsea noise from marine renewable energy developments are being studied (Gill et al., 2012).

In a systematic review of published scientific studies on the potential ecological effects of radiofrequency electromagnetic fields (RF-EMF) in the range of 10 MHz–3.6 GHz, about two thirds of the reviewed studies show ecological effects of RF-EMF at high, as well as at low, dosages (Cucurachi et al., 2013). The low dosages are compatible with real field situations, and could be found under environmental conditions (Cucurachi et al., 2013; Balmori, 2014). However, studies conducted in real field situations must be made with a sufficient experimental exposure time, since results with a short period of exposure are likely to be ambiguous (e.g. 48 h in Vijver et al., 2013).

A limited number of studies have addressed the effects of radiofrequency radiation on plants indicating that these effects depend on the plant family, growth stage, exposure duration, frequency, and power density, among other factors (Senavirathna and Takashi, 2013; Halgamuge et al., 2015). There are two papers warning on negative effects of radio frequencies from mobile phone masts on trees (Balmori, 2004; Waldmann-Selsam and Eger, 2013) and researchers have found very worrying effects in laboratory studies (Pesnya and Romanovsky, 2013). The results of these preliminary findings indicate that further research on this topic is extremely urgent.

These results could have important implications for wildlife, especially in urban and suburban areas, but also in rural, natural and protected areas where there are powerful base station emitters of radiofrequencies (Bürgi et al., 2014). Such effects have not yet been examined, but the consequences continue due to the fact that the existing guidelines of public health protection only consider the effects of short-term thermal exposure (Hyland, 2000) and do not adequately protect wildlife. EMF safety standard should be based on the more sensitive, natural biological response (Blank, 2014). Therefore, more research on the effects of electromagnetic radiation in nature is needed to investigate this emerging threat (Balmori, 2014).

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