Ressortforschungsberichte zum Strahlenschutz

Internationaler Workshop zum Einfluss elektrischer, magnetischer und elektromagnetischer Felder auf die belebte Umwelt
- Vorhaben 3619I02420

Auftragnehmer:
Valentum Kommunikation GmbH

Das Vorhaben wurde mit Mitteln des Bundesministeriums für Umwelt, Naturschutz und nukleare Sicherheit (BMU) und im Auftrag des Bundesamtes für Strahlenschutz (BfS) durchgeführt.

Bundesamt für Strahlenschutz

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Salzgitter, April 2020

Abschlussbericht

Vorhaben: 3619I02420

International Workshop: Environmental effects of electric, magnetic and electromagnetic fields: Flora and fauna

Auftragnehmer:
Valentum Kommunikation GmbH
Bischof-von-Henle Straße 2b
93051 Regensburg

Laufzeit des Vorhabens: Juli 2019 bis Februar 2020

Anlagen:
Veranstaltungsprogramm
Abstractband

1. Zielsetzung

Die Einrichtung zahlreicher neuer Stromnetze im Zuge der Energiewende, der Ausbau der 5G-Technolgie in der Telekommunikation sowie generell die Ausweitung neuer Technologien im Alltag setzen die Umwelt immer stärker elektrischen, magnetischen und elektromagnetischen Feldern aus, deren Wirkungen auf Flora und Fauna nur teilweise bekannt sind. Das führt zunehmend zu Bedenken in der Bevölkerung hinsichtlich gesundheitlicher Auswirkungen sowie möglicher Folgen für Tiere und Pflanzen.

Im Rahmen einer dreitägigen öffentlichen Veranstaltung wurde der aktuelle Forschungsstand mit internationalen Experten umfassend beleuchtet, um sich der Thematik aus unterschiedlichen wissenschaftlichen Perspektiven zu nähern, Wissenslücken zu identifizieren und neue Forschungsaufgaben herauszuarbeiten.

1.1 Einzelzielsetzung

Unmittelbares Ziel der Veranstaltung war es, einen Überblick über den aktuellen Forschungsstand aus unterschiedlichen Perspektiven zu erhalten sowie wichtige neue Gebiete und offene Fragen zu identifizieren, auf deren Grundlage die Forschung fortgeführt werden sollte. Hierfür wurden internationale Referentinnen und Referenten aus verschiedenen Forschungsfeldern nach München eingeladen, um sich der Thematik möglicher Effekte von magnetischen, elektrischen und elektromagnetischen Feldern auf Pflanzen und Tieren von verschiedenen Seiten anzunähern. Weitere Beiträge konnten in dem öffentlichen Workshop eingereicht werden. Erweitert wurde der Teilnehmerkreis durch weitere Expertinnen und Experten, die den Workshop als Teilnehmende mit ihrem Fachwissen ergänzten.

Der Workshop wurde in vier inhaltlich aufeinander abgestimmte Sessions eingeteilt.

Die inhaltlichen Details und Vorbereitungen des Workshops wurden vom Bundesamt für Strahlenschutz erarbeitet. Die organisatorische Umsetzung erfolgte mit Unterstützung eines externen Dienstleisters (Valentum Kommunikation GmbH).

1.2 Voraussetzungen für den Workshop

Der Workshop fand im Tagungssaal des Salesianums, Don Bosco in München Haidhausen-Au statt. Der Veranstaltungsort ist sowohl vom Flughafen als auch vom Hauptbahnhof mit einer direkten S-Bahn Verbindung in ca. 30 Minuten zu erreichen. Das Tagungscatering wurde durch den Veranstaltungsort geleistet.

1.3 Planung und Ablauf des Workshops

Die Aufgaben für die Organisation des Workshops wurden in drei Arbeitspakete eingeteilt.

AP 1: Planung des Workshops:

- Auswahl eines Veranstaltungsortes und des Termins
- Management der Einladungen und Ankündigungen, Organisation der Pausenversorgung
- Einrichtung der notwendigen technischen Infrastruktur
- Einrichtung und Führung eines Tagungsbüros
- Reisemanagement der Teilnehmenden
- Organisation eines gemeinsamen Conference Dinners
- Einladungsversand

AP 2: Durchführung des Workshops

- Unterstützung bei der Einhaltung des Programmablaufs (siehe Anhang)
- Koordination der Dienstleister vor Ort (Technik, Catering, Conference Dinner)
- Betreuung der Rednerinnen und Redner sowie Gäste vor Ort (Reisemanagement, Registrierung, Beantwortung von organisatorischen Rückfragen)

AP 3: Nachbereitung

- Fotodokumentation
- Reisekostenabrechnung
- Abschlussbericht

1.4 Organisatoren

Die dreitägige Veranstaltung „International Workshop: Environmental effects of electric, magnetic and electromagnetic fields: Flora and fauna“ wurde vom Bundesamt für Strahlenschutz durchgeführt.

Die Organisation und praktische Durchführung wurde durch die Agentur Valentum Kommunikation GmbH (Bischof-von-Henle Straße 2b | 93051 Regensburg) unterstützt.

2. Durchführung des Workshops

2.1 Hintergrund

Alleiniger Veranstalter des Workshops, der vom 5. bis 7. November 2019 in München stattfand, war das Bundesamt für Strahlenschutz im Auftrag des Bundesministeriums für Umwelt, Naturschutz und nukleare Sicherheit. Unmittelbar nach dem Auftaktgespräch am 3. Juli 2019 wurde die Veranstaltungswebseite www.emf-environment-workshop.de eingerichtet. Hier wurden laufend aktuelle Informationen zum Programm und dem Ablauf der Tagung sowie die Möglichkeit zur Registrierung bereitgestellt.

2.2 Programm

Mit 23 Vorträgen von geladenen Rednerinnen und Rednern aus neun Ländern wurde das Programm des dreitägigen Workshops gestaltet. Zusätzlich ergänzten vier Kurzvorträge von teilnehmenden Gästen das Programm. Folgende Fragen sollten im Rahmen der Veranstaltungen erarbeitet werden und dienten als Grundlage der Diskussionen:

- What are the effects of electric, magnetic and electromagnetic fields (EMF) on animals, plants and ecosystems? What are the responses to natural or environmental fields, like behavior, orientation?
- Are the natural responses (see above) disturbed by anthropogenic EMF of a certain frequency range?
- Are there any direct adverse effects of anthropogenic EMF, like tissue damage, death, disturbance of ecosystems?
- Where do we have open questions and research gaps?
- How to close these gaps, research suggestions and recommendations?

Zwischen den Programmpunkten konnte das Publikum Fragen zu den Präsentationen stellen und Probleme oder Streitpunkte diskutieren. Den Abschluss des jeweiligen Veranstaltungstages bildete eine ausführliche Diskussionsrunde. Teilnehmende, Rednerinnen und Rednern und Veranstalter tauschten sich hier noch einmal über das Gehörte aus und erörterten gemeinsam Ansatzpunkte für die Weiterentwicklung der Forschung. Auf Basis des erhaltenen Feedbacks wird nun die weitere Vorgehensweise erarbeitet.

In den Programmpausen sowie bei einem gemeinsamen Conference Dinner am Abend des zweiten Veranstaltungstags konnten die Gäste den Austausch sowie das Networking im lockeren Rahmen fortsetzen.

Insgesamt nahmen 64 Personen aus 15 Ländern am Workshop teil. Die Teilnahmegebühr betrug 200 Euro, zuzüglich 50 Euro für eine Teilnahme am Conference Dinner.

2.3 Beteiligte Akteure des Workshops

Geladene Rednerinnen und Redner

- Ahmad, Margaret | Sorbonne University, France
- Bolte, John | National Institute for Public Health and the Environment, The Netherlands
- Geschwentner, Dirk | Federal Office for Radiation Protection, Germany
- Gill, Andrew | Lowestoft Lab, Suffolk, UK
- Gordon, Chris | U.S. Environmental Protection Agency, USA
- Hässig, Michael | University of Zurich, Switzerland
- Holland, Richard A. | School of Natural Sciences, Bangor University, UK
- Kattnig, Daniel | Department of Physics, University of Exeter, UK
- Kirshvink, Joe | California Institute of Technology, USA
- Kuhne, Jens| Federal Office for Radiation Protection, Germany
- Lazaro, Amparo | Mediterranean Institute for Advanced Studies, Spain
- Maffei, Massimo E. | Department Life Sciences and Systems Biology, University of Turin, Italy
- Malkemper, Pascal | Max-Planck Institute Caesar, Germany
- Mouritsen, Henrik | Carl-von-Ossietzky-University of Oldenburg, Germany
- Paffhausen, Benjamin | Freie Universität Berlin, Germany
- Robert, Daniel | School of Biological Sciences, University of Bristol, UK
- Schmaljohann, Heiko | Vogelwarte Helgoland, Helgoland
- Schmid, Gernot | Seibersdorf Laboratories, Austria
- Thielens, Arno | University of California Berkeley, Berkeley Wireless Research Center, UK
- Vanbergen, Adam | INRA science & impact, France
- Vian, Alain | University of Angers, France
- Winklhofer, Michael | Carl-von-Ossietzky-University of Oldenburg, Germany

Teilnehmerinnen und Teilnehmer, die Kurzvorträge eingereicht haben

- Czerwinski, Marek | Poznań University of Life Sciences, Poland
- Eder, Stephan | Technical University Munich, Germany
- Vácha, Martin | Masaryk University, Czech Republic
- Waldman-Selsam, Cornelia | Germany

3. Ergebnisse

Für einen Überblick über den während des Workshops präsentierten Forschungsstand sind im Anhang die eingereichten Abstracts beigefügt.

Kosten- und Zeitplanung wurden eingehalten.

Programme

Tuesday, November 5th

From 11.00 am	Registration │ Welcome coffee & snacks
12.00 – 12.15 am	Official welcome *Gunde Ziegelberger, Federal Office for Radiation Protection*
	Session 1: Exposure Assessment and Dosimetry ***Chair: Jens Kuhne, Federal Office for Radiation Protection***
12.15 – 12.45 am	Low frequency and static electric and magnetic fields – Power lines and cables *Jens Kuhne, Federal Office for Radiation Protection*
12.45 – 1.15 pm	Intermediate frequencies – Possible exposure of animals during wireless car charging *Gernot Schmid, Austria*
1.15 – 1.45 pm	Radiofrequency electromagnetic field exposure from fixed installations like broadcast stations or (5G) mobile radio base stations *Dirk Geschwentner, Federal Office for Radiation Protection*
1.45 – 2.15 pm	Exposure of insects to environmental radio-frequency electromagnetic fields *Arno Thielens, Belgium/USA*
2.15 – 2.45 pm	Coffee break
	Session 2: Action mechanisms ***Chair: Jens Kuhne, Federal Office for Radiation Protection***
2.45 – 3.15 pm	Thermoregulatory response to the heat stress from exposure to RF radiation: Extrapolation from experimental mammals to humans *Christopher Gordon, USA*
3.15 – 3.45 pm	Thermal stress in the NTP-Study *Jens Kuhne, Federal Office for Radiation Protection*
3.45 – 4.15 pm	Role of magnetite in animal orientation: Working hypothesis and experimental evidence *Michael Winklhofer, Germany*
4.15 – 5.00 pm	Towards a mechanistic understanding of anthropogenic magnetic field effects: The Radical-Pair mechanism and new insights from spin physics *Daniel Kattnig, UK*
	Poster Session
5.00 – 6.00 pm	Equipment related bias in behavioural experiments with magnetic field conditions *Stephan H. K. Eder, Germany*
From 7.00 pm	Informal get-together Wirtshaus in der Au | Lilienstr. 51 | 81669 Munich

Wednesday, November 6th

From 8.30 am	Registration │ Welcome coffee & snacks
	Session 3: Low frequency electric and magnetic fields: Powerlines and cables
	Session 3.1: Effects of electric and magnetic fields on vertebrates ***Chair: Blanka Pophof, Federal Office for Radiation Protection***
9.00 – 9.30 am	Subsea cables, electromagnetic fields and their potential impact on marine animals *Andrew Gill, UK*
9.30 – 10.15 am	Electromagnetic noise effects on the magnetic compass of night-migratory songbirds via a Radical-Pair mechanism *Henrik Mouritsen, Germany*
10.15 – 10.45 am	Does anthropogenic electromagnetic noise disturb the orientation ability of free-flying birds? *Heiko Schmaljohann, Germany*
10.45 – 11.15 am	Coffee break
11.15 – 11.45 am	A magnetic sense in bats? Evidence and knowledge gaps *Richard Holland, UK*
11.45 – 12.30 am	Magnetoreception in mammals *Pascal Malkemper, Germany*
	Session 3.2: Effects of radiofrequency electromagnetic fields on vertebrates **Chair: Blanka Pophof, Federal Office for Radiation Protection**
12.30 – 1.00 pm	Effects of electromagnetic fields on dairy cows *Michael Hässig, Switzerland*
1.00 – 2.00 pm	Lunch break
	Session 3.3: Effects of electric and magnetic fields on invertebrates **Chair: Blanka Pophof, Federal Office for Radiation Protection**
2.00 – 2.30 pm	Electrosensitivity and electric ecology in insects *Daniel Robert, UK*
2.30 - 3.00 pm	Social communication in the honeybee colony with temporal electrostatic field patterns *Benjamin Paffhausen, Germany*
3.00 – 3.15 pm	Insect circadian rhythm responds to weak radiofrequency field *Martin Vácha, Czech Republic*
	Session 3.4: Effects of electric and magnetic fields on plants **Chair: Janine Schmidt, Federal Office for Radiation Protection**
3.15 – 3.45 pm	The effect of magnetic fields on plant growth development and evolution *Massimo Maffei, Italy*
3.45 – 4.15 pm	Role of cryptochromes in magnetoreception of plants and animals *Margaret Ahmad, France*

4.15 – 5.00 pm	Coffee break
	Evening lecture
5.00 – 6.00 pm	Human magnetoreception: Biophysical mechanisms and thresholds *Joseph Kirschvink, USA*
From 7.00 pm	Conference Dinner Hofbräukeller am Wiener Platz	Innere Wiener Straße 19	81667 München

Thursday, November 7th

From 8.30 am	Registration │ Welcome coffee & snacks
	Session 4: Radiofrequency electromagnetic fields – Mobile communications including 5G
	Session 4.1: Effects of electromagnetic fields on plants ***Chair: Janine Schmidt, Federal Office for Radiation Protection***
9.00 – 9.30 am	Plant responses to high frequency electromagnetic fields: From gene expression to morphological changes *Alain Vian, France*
9.30 – 9.45 am	The influence of bioactive mobile telephony radiation at the level of a plan community – possible mechanisms and indicators of the effects *Marek Czerwinski, Poland*
9.45 – 10.00 am	Radiofrequency radiation injures trees around mobile phone base stations *Cornelia Waldmann-Selsam, Germany*
	Session 4.2: Effects of electromagnetic fields on invertebrates ***Chair: Blanka Pophof, Federal Office for Radiation Protection***
10.00 – 10.30 am	Risk to pollinators from anthropogenic electro-magnetic radiation (EMR): Evidence and knowledge gaps *Adam Vanbergen, France*
10.30 – 11.00 am	Electromagnetic radiation of mobile telecommunication antennas affects the abundance and composition of wild pollinators *Amparo Lázaro, Spain*
11.00 – 11.30 am	Coffee break
11.30 – 12.00 am	Ecological effects of electromagnetic fields on invertebrates *John Bolte, The Netherlands*
12.00 – 1.00 pm	Discussion: Knowledge gaps and research perspectives *Chair: Blanka Pophof, Federal Office for Radiation Protection*
1.00 – 2.30 pm	Buffet & Adjourn

Bundesamt für Strahlenschutz

International Workshop: Environmental effects of electric, magnetic and electromagnetic fields: Flora and fauna

5th – 7th November 2019 | Munich

Session 1: Exposure Assessment and Dosimetry

Low frequency and static electric and magnetic fields – Power lines and cables

Jens Kuhne | Federal Office for Radiation Protection

In a power grid, overhead power lines or underground cables are used to distribute the electrical energy generated in power plants. Depending on technology the surrounding environment of the conductors is exposed to static or low frequency electric and magnetic fields. Based on recognized scientific knowledge, compliance with the guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) protects against known detrimental effects. However, these guidelines are established for the protection of humans and research regarding the impact of the fields on flora and fauna is ongoing.

For a correct scientific assessment of field induced effects on plants or animals, reliable exposure data is of great importance. As a number of factors influence the field distribution pattern of electrical energy supply systems, great care is required for a proper dosimetric assessment.

Intermediate frequencies – Possible exposure of animals during wireless car charging

Gernot Schmid | Seibersdorf Laboratories, Austria

Wireless power transfer (WPT) systems for electric vehicle charging will become widespread in future automotive scenarios. Inductive resonant WPT systems have turned out as the most promising technology as they allow efficient power transfer over a separation distance (gap) between transmitter and receiver coil of up to approximately 20 cm. Transmission frequencies are usually in the range 20 kHz – 90 kHz (for passenger vehicles typically 85 kHz) and power ratings range from several kW up to 100 kW. In the gap between primary (transmit) and secondary (receive) coils magnetic flux densities may reach several tens of mT, i.e. far above reference levels and actions levels presently applied for human exposure assessment. Even laterally outside the gap the stray field may reach values above the mentioned reference levels.

In practice, it can be expected that small animals (mice, rats, hamsters, cats, small dogs, etc.) may closely approach the WPT system or, if there is no appropriate non-metallic object detection implemented in the WPT system, even move into the gap during charging. Consequently, high exposure of such animals may occur in such situations.

From the European regulation point of view, WPT systems have to comply with the requirements of directive 2014/35/EU ("Low Voltage Directive") which explicitly includes the "…protection of health and safety of persons, and of domestic animals …" in its basic requirements.

Available data about exposure of animals due to WPT systems is very scarce so far. The only available publication dealing with this issue analyzed the induced electric field inside a simple (homogeneous) numerical model of a cat (Wang et al. 2018, IEEE Trans EMC), laterally approaching a 85 kHz / 10 kW WPT system with 15 cm gap. The magnetic flux density in the region of the cat's body ranges between 26 ↔T and 3 mT, leading to a maximum induced electric field value inside the tissue of 21.6 V/m, which is still below, e.g., the occupational exposure limit value according to European workers' directive 2013/35/EU and the basic restrictions for occupational exposure according to ICNIRP 2010.

In order to estimate maximum induced electric field strength Ei even for animals inside the gap we carried out numerical computations using differently sized highly detailed anatomical rat models distinguishing more than 40 different body tissues, assuming exposure by an 85 kHz WPT system with square coils (primary coil 70 cm x 70 cm, secondary coil 60 cm x 60 cm). The size of the largest rat model was chosen such that it just fits into the 10 cm gap of the WPT system. Currents inside the coils were chosen according to Wang et al 2018 and scaled to represent transmit power values of 5 kW, 20 kW and 100 kW, respectively. Three different positions of the rat model inside the gap and next to the WPT system were considered, respectively: (a) in the center of the WPT system on the surface of the primary coil (inside the gap); (b) at the edge of the WPT system, above the wires of the primary coil; (3) laterally beside the WPT system, approx. 5 cm lateral to the edge of the primary coil. Assuming a dominant magnetic exposure condition for the animals, the computations were carried out using the magneto-static solver of the SEMCAD X simulation platform, i.e. neglecting any impact of the incident electric field. The maximum 2 x 2 x 2 mm3 volume average of the induced electric field strength maxEi,avg inside the tissues was evaluated as the relevant dosimetric quantity.

As expected maxEi,avg is highest in large animals, particularly when placed on top of the wires of the primary coil. The highest obtained maxEi,avg values for 5 kW, 20 kW and 100 kW were 28 V/m, 56 V/m and 126 V/m, respectively. These values are above the occupational basic restrictions but still below what is presently assumed to be the stimulation threshold of mammalian nerve cells.

In view of the expected wide variety of construction details of WPT systems and animal anatomy, these results should be seen only as rough estimates. However, from these results, it appears unlikely that animals are in acute danger due to exposure caused by WPT systems for electric vehicle charging. As an important note it must be mentioned that these results can only be valid for cases where the animals do not incorporate metallic parts. Particularly for pets, metallic implants (e.g. after bone fractures) become more and more frequent. In such a case severe thermal tissue damage may occur due to induction heating of the implant.

Radiofrequency electromagnetic field exposure from fixed installations like broadcast stations or (5G) mobile radio base stations

Dirk Geschwentner | Federal Office for Radiation Protection

High power radio-frequency transmitters are used for providing terrestrial radio and TV broadcast services. Only a small number of transmitters are necessary for coverage over large areas. In contrast, public mobile communications require a dense network of fixed transmitter with significantly less transmitting power at each site. Both types of transmitters emit radio-frequency radiation (RFR) into the surrounding environment. Immissions or exposure levels can be measured and assessed in terms of power density and/or electric field strength levels. Compared to international guidelines, typical exposures are quite low at places where humans may stay. Nevertheless, exposure patterns can vary significantly depending on time and space.

As a matter of principle, good quality research on possible RFR induced biological and health effects needs good quality exposure data. This holds true for research in humans and in animals or plants. The presentation aims at giving a brief overview of exposure assessments in the nearer and further vicinity of transmitter sites and relevant factors that influence the exposure level.

Exposure of insects to environmental radio-frequency electromagnetic fields

Arno Thielens | University of California Berkeley, Department of Electrical Engineering and Computer Sciences, USA | Department of Information Technology, Belgium

Wireless telecommunication uses radiofrequency (RF) electromagnetic fields (EMFs) to interchange information between billions of individuals worldwide. The current networks mainly operate at frequencies between 100 MHz and 6 GHz and are the dominant source of outdoor exposure to RF-EMFs [1]. However, due to increased numbers of users and demand in bandwidth, it is expected that future networks will also use carrier frequencies higher than 6 GHz, up to 300 GHz [2]. RF-EMFs can be absorbed in insects [3, 4]. This abstract presents a study of this absorption using numerical simulations [3]. A commonly used technique for such simulations is the finite-difference time-domain (FDTD) algorithm, which relies on measurements of dielectric parameters [4] and the development of accurate 3D models with relatively high spatial resolution, i.e. small model features relative to the studied wavelengths. Our research showed that X-ray micro-tomography (micro-CT) can be used to obtain models for a set of insects [3, 5] with sufficient spatial resolution for FDTD in the frequency range of interest. Dielectric parameters for insects were obtained from a literature survey [3]. These models and parameters were used in FDTD simulations to investigate far-field exposure to RF-EMFs in the 0.6 to 120 GHz range. These simulations were combined with in-situ measurements of environmental RF-EMF exposure to estimate realistic exposure and absorbed power values for the studied insects. The results showed that the absorbed power in insects depend on the insect morphology and frequency. In the 0.6 - 6 GHz frequency range, RF-EMF absorption increased with frequency for all the studied insects. The RF-EMF absorption was either constant or increased with frequency in the 6 - 120 GHz range. This implies that insect exposure to RF-EMFs might increase in future telecom networks.

References:

[1] Bhatt, CRR., et al. Assessment of personal exposure from radiofrequency-electromagnetic fields in Australia and Belgium using on-body calibrated exposimeters. Environ. Res. 151, 547–563, 2016.

[2] Colombi, D, Thors, B, Tornevik, C. Implications of emf exposure limits on output power levels for 5 G devices above 6 Ghz. IEEE Antennas Wirel. Propag. Lett. 14, 1247–1249, 2015.

[3] Thielens, A, Bell, D, Mortimore, DB, Greco, MK, Martens, L, Joseph, W. Exposure of Insects to Radio-Frequency Electromagnetic Fields from 2 to 120 GHz, Nature Scientific Reports 8(1), 3924, 2018.

[4] Nelson, SO. Review and assessment of radio-frequency and microwave energy for stored-grain insect control. Transactions ASAE 39, 1475–1484, 1996.

[5] Greco, M, Tong, J, Soleimani, M, Bell, GD, Schafer, MO. Imaging live bee brains using minimally-invasive diagnostic radioentomology. J. Insect Sci. 12, 1–7, 2012.

Session 2: Action mechanisms

Thermoregulatory response to the heat stress from exposure to RF radiation: Extrapolation from experimental animals to humans

Christopher Gordon | U.S. Environmental Protection Agency, USA

Exposure to RF radiation can result in an elevation in body temperature leading to heat stress. To maintain thermal homeostasis, the thermoregulatory system utilizes multiple autonomic and behavioral strategies to either reduce heat production or increase heat loss when exposed to RF radiation. When faced with an RF heat load, the body's heat production is reduced and peripheral vasodilation and sweating are activated to increase heat loss. Behavioral thermoregulatory responses, such as seeking a cooler environment, is indeed the most sensitive thermoeffector utilized to minimize thermal stress. Like humans, mice and rats are able to regulate a relatively stable core temperature over a wide range of ambient temperature. Humans are better adapted to maintain a stable core temperature during heat stress. However, since the dose of RF radiation is typically normalized to body mass (i.e., W/kg), small rodents are actually better adapted at thermoregulating when exposed to high doses of RF radiation.

That is, there is an allometric relationship between efficacy of RF radiation to induce hyperthermia that is inversely dependent on body size. For example, the SARs required to elevate core body temperature by 1 °C in 90 min for a 22 g mouse, 107 g hamster, 417 g rat, and 3075 g rabbit maintained at an ambient temperature of 20 °C are, respectively; 57.1 W/kg, 17.4 W/kg, 3.3 w/kg, and 1.4 W/kg. As body mass decreases, surface area: Body mass increases, allowing for a rapid rate of heat dissipation by convection, conduction, and radiation. In comparing mouse to an adult human, significant thermoregulatory responses in the mouse are detected at SAR's of 10-30 W/kg while similar thermoregulatory responses in humans are observed at SARs below 1 W/kg. In view of the allometric relationship between body mass and the threshold SAR to elevate core temperature, extrapolating from rodent to human requires one to use a higher SAR in the rodent model to mimic a similar thermoregulatory response in an adult human.

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Thermal stress in the NTP-Study

Jens Kuhne | Federal Office for Radiation Protection

Last year, the final reports of a large two year study on mice and rats exposed to chronic cell phone radiofrequency radiation (RFR) were published by the National Toxicology Program (NTP)[1,2]. The most prominent effects were observed in male rats. The NTP concluded that there is clear evidence of carcinogenic activity of GSM and CDMA modulated RFR in male rats based on a correlation between exposure and incidences of malignant schwannoma in the heart. Assuming that the observed effects are indeed related to exposure, we discuss the results of the NTP-study in the context of thermal stress. Taking into account the results of the temperature measurements in the pilot studies [3] performed in order to set appropriate SAR for the two-year study, we hypothesize that significant body temperature fluctuations in adult male rats might be associated with some of the findings. Suggestions how to improve future study designs are made.

References:

[1] National Toxicology Program, Technical Report 595 (2018), Available from: https://ntp.niehs.nih.gov/go/tr595.
[2] National Toxicology Program, Technical Report 596 (2018), Available from: https://ntp.niehs.nih.gov/go/tr596.
[3] Wyde, Michael E., et al. "Effect of cell phone radiofrequency radiation on body temperature in rodents: Pilot studies of the National Toxicology Program's reverberation chamber exposure system." Bioelectromagnetics 39.3 (2018): 190-199.

Role of magnetite in animal orientation: Working hypothesis and experimental evidence

Michael Winklhofer | University of Oldenburg, Germany

The magnetite hypothesis for magnetic-field sensory reception assumes specialized cells containing ferrimagnetic particles. Of all known biogenic ferrimagnetic materials, magnetite (Fe_3O_4) has the highest spontaneous magnetization and therefore is most suitable for realizing an effective sensor for the primary interaction with the weak ambient magnetic field. A straightforward way of detecting the magnetic field in an animal would be via single-domain magnetite (50 nm particle size) connected to mechanosensitive ion-channels, which in turn could directly transduce the mechanic response of the particles in a magnetic field [1]. Other mechanisms based on superparamagnetic nanoparticles (less than 10 nm particle size) are physically feasible, too [2], but generally not so efficient. The trigeminal nerve, as part of the somatosensory system, has been shown to be involved in the magnetic sensing pathway, in both fish (salmonids) [3] and migratory birds [4]. Since the trigeminal nerve innervates mechanosensory nerve endings in the periphery, it is therefore likely to transmit also magnetic information from magnetically gated mechanosensitive ion channels. The best structural evidence for a magnetite-based sensor is from trigeminally innervated tissue in the nose rainbow trout [5], although the nature of the cell type hosting the magnetite particles remains to be identified, even 20 years after it was described. The experimental observations that magnetic orientation in salmon [6] and subterranean mole rats [7] depends on the polarity of the ambient magnetic field, is consistent with a mechanism based on single-domain magnetite. Effects of a strong (100 mT) but brief (1 msec) magnetic pulse on spontaneous orientation preferences of birds are consistent with magnetite, too, but need better controlled sham conditions to rule out magnetic induction artefacts. Magnetic sensing based on magnetite may be affected, at least theoretically, by extremely low-frequency magnetic fields (< 100 Hz) of moderate strength (1 μT) [8]. In contrast, heating through magnetic relaxation effects is practically negligible under weak [<μT] radio-frequency magnetic fields (< 10 MHz) as used in testing for radical-pair based magnetoreception [9]. Either way, to quantitatively assess effects of magnetic fields of any frequency on magnetoreceptor cells, we require candidate cells, which are not directly accessible yet. Contamination of animals with magnetic fine dust from the environment is a major problem in the identification of candidate cells just by their magnetic signature. This also applies to studies on the yet unknown role of magnetite in the human brain.

References:

[1] Winklhofer, M & Kirschvink, JL (2010) J. Roy. Soc. Interface 7, 273 - 289.
[2] Davila, AF, Fleissner, G, Winklhofer, M, Petersen, N (2003) J. Phys. Chem. Earth. 28, 647-652.
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[4] Pakhomov, A, et al. (2018) Sci. Rep. 8, 11975.
[5] Diebel, C, et al. (2000) Nature 299, 298-302
[6] Quinn, T.P, Merrill, RT, Brannon, EL (1981) J. Exp. Zool. 217, 137-142.
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[8] Polk, C (1994) Bioelectromagnetics 15, 261-270.
[9] Shcherbakov, VP & Winklhofer, M (2010) Phys. Rev. E 81, 031921.

Towards a mechanistic understanding of anthropogenic magnetic field effects: The Radical Pair mechanism and new insights from spin physics

Daniel Kattnig | University of Exeter, UK

The Radical Pair Mechanism (RPM) is widely considered as the canonical model for the magnetosensitivity of chemical reaction processes in weak magnetic fields [1]. Its governing principle is the coherent interconversion of the singlet and triplet spin states of a radical pair, the key ingredient to which is the hyperfine interaction. This, in combination with spin-selective reaction channels, gives rise to magnetic field effects (MFEs) in the reaction yields. This model might underpin the magnetic compass attributed to many migratory birds in the form of the blue-light sensitive flavo-protein cryptochrome [1]. The RPM is also discussed in the context of putatively adverse health effects resulting from the exposure to weak static and oscillatory magnetic fields [2]. This truly quantum mechanism is now at the forefront of the emerging field of quantum biology.

Here, I will describe the key features of the RPM followed by a discussion of two new aspects of reaction magnetosensitivity that have merged from recent research of our group.

First, I will show that the hyperfine interaction is not a categorical requirement to realize magnetosensitivity to weak magnetic fields. Instead, in systems comprising more than two radicals, dipolar interactions provide an alternative, so far undiscovered, pathway for MFEs [3]. By considering the role of symmetries and energy level crossings, I will present a model that demonstrates a directional sensitivity to fields weaker than the geomagnetic field, and remarkable spikes in the reaction yield, as a function of the magnetic field intensity, that can be tuned by the exchange interaction. These results further our current understanding of weak-field reaction magnetosensitivity and could be particularly relevant to MFEs on lipid autoxidation [4].

Second, I will report on a surprising effect that can boost the magnetosensitivity of radical pairs in the putative magnetosensory protein cryptochrome [5,6]. We have found that MFEs can be vastly amplified if one of the radicals of the primary pair undergoes a spin-selective electron transfer reaction with a spin-bearing scavenger (chemical Zeno effect). This new scheme offers clear and important benefits such as a greatly enhanced sensitivity to the orientation of a 50 μT magnetic field and immunization the sensor to fast decoherence processes in one of the radicals. Consequently, magnetic field effects on radical pairs involving swiftly spin-relaxing species, such as superoxide, are no longer to be precluded, but could even be desirable. This is remarkable insofar as some evidence has recently emerged in favor of a magnetosensitive reoxidation reaction in cryptochrome involving superoxide.

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Poster Session

Equipment related bias in behavioural experiments with magnetic field conditions

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During the last decades many analyses on interactions of magnetic fields with living organism have been performed. In order to archive reliable and non-biased results in behavioural experiments as well as in in-vitro experiments, the following guidelines for the experimental setup should be considered:
(i) As a proper control in magnetic field experiments it is mostly not sufficient to switch off the magnetic field. However a double-winded coil setup with exact windings is needed, in order to allow for anti-parallel currents that generate an emerged field of exactly zero. Else, other cues than the magnetic can play into the results. Additionally, in some experiments it is useful to have a third wrap on the coils that compensates the ambient magnetic field (i.e. Earth's magnetic field).
(ii) Double blind experiments reduce the potential bias of human interactions. It is recommended to perform the experimental sequences automated and computer-controlled. This requires bipolar power supplies that are controlled by computer outputs, such as bipolar amplifiers.
(iii) Avoidance of acoustic noise that is generated by coils or amplifiers. Many amplifiers have strong active cooling that produces massive acoustic noise, and therefore can bias the tested animals or living objects. Secondly, magnetic field coils can produce acoustic noise when their wires are not completely fixed.
(iv) Avoidance of electric noise and electric fields that are generated through amplifiers or coils. Many amplifiers and power supplies use pulse width modulation (PWM) for regulating the power. This induces ripples in the magnetic field and could also generate electric fields as consequence.
(v) Robustness of equipment for reproducible results. Here we illustrate how experimental equipment should be designed to enhance the power of experimental results.

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Session 3: Low frequency electric and magnetic fields: Powerlines and cables
Session 3.1: Effects of electric and magnetic fields on vertebrates

Subsea cables, electromagnetic fields and their potential impact on marine animals

Andrew Gill | Lowestoft Lab, UK

Anthropogenic electromagnetic fields are emitted into the marine environment by devices and cables which add to natural magnetic (e.g. geomagnetic field) and electric fields (e.g. bioelectric fields). Many marine organisms from the smallest bacteria to the largest mammals are able to detect and respond to the natural emissions but our knowledge relating to whether they respond to anthropogenic sources (e.g. subsea cables) is poor. Current understanding on the topic shows that there are published cases of EM-sensitive animals responding to anthropogenic EMF sources in the marine environment and other more equivocal findings. Some of these are field studies, which focus on species assemblages or behavioural responses of mobile (or migrating) species, whilst other more laboratory-base studies give developmental or physiological insight. Each of these studies improves the knowledge base to a degree, however, our interpretation of whether the study results are biologically meaningful suffers from lack of knowledge on the EMF emitted, whether it is A.C. or D.C. and how the response by the organisms is determined. Whilst EMF- marine animal interaction may appear only of interest as a local biological topic, the emission of low frequency electromagnetic fields, such as when transmitting power through cables, increasingly will require specific consideration with regards to mandatory environmental impact assessment (EIA). Furthermore, as subsea cables design moves towards increasing the power carried and more cables and networks are deployed, appropriately assessing the potential environmental impact associated with EMF will need to be incorporated into the overall assessment of cable installation impact (including cable characteristics, route choice and electrical transmission type). A framework is suggested to enable the EMF-animal interaction to be taken into account appropriately, where necessary, for those involved with marine subsea cables and potentially the wider marine electromagnetics industry.

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Electromagnetic noise effect on the magnetic compass of night-migratory songbirds

Henrik Mouritsen | University of Oldenburg, Germany

Night-migratory songbirds use a magnetic compass as one of their most important tools to find their way over thousands of kilometres (Mouritsen 2018). Neuroanatomical data have shown that magnetic compass information is detected in the eye and then processed in a small part of the visual brain pathway terminating in "Cluster N" (Mouritsen et al. 2005; Zapka et al. 2009). When Cluster N is deactivated, migratory European Robins can no longer use their magnetic compass, whereas their star compass and sun compass abilities are unaffected (Zapka et al. 2009). Over the past years, evidence has mounted that migratory birds use a light-dependent, radical pair-based mechanism to sense the compass direction provided by the geomagnetic field lines (Hore & Mouritsen 2016). In a large series of double-blinded experiments performed over more than a decade, we have shown that the magnetic compass of night-migratory birds is sensitive to anthropogenic electromagnetic fields at least in the frequency range 400 kHz - 10 MHz being ca. 1000 times weaker than the current WHO guideline limits (Engels et al. 2014; Schwarze et al. 2016; Kobylkov et al. in revision). While these fully double-blinded tests document a reproducible effect of anthropogenic electromagnetic noise on the behaviour of an intact vertebrate, they do not allow us to deduct the presence or absence of effects of RF-Noise on human beings. The disruptive effects on the birds' magnetic compass cannot be attributed to power lines (16.7 Hz or 50 Hz fields) or to mobile phone signals (100MHz to GHz frequencies), since such disturbances are not expected to affect a radical-pair mechanism.

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Does anthropogenic electromagnetic noise disturb the orientation ability of free-flying birds?

Heiko Schmaljohann | Vogelwarte Helgoland, Germany

Most of our fundamental knowledge of magnetoreception and orientation/navigation in birds is based on cage experiments under controlled laboratory conditions. In contrast, studies testing whether free-flying birds use magnetic cues for orientation/navigation in the wild are scarce. To study the biological significance of the proposed magnetoreception mechanisms, i.e., magnetic-particle-based and radical-pair mechanism, in free-flying birds is, therefore, still a major challenge. This is so because birds have to be rather large and robust to be equipped with devices manipulating the magnetic sensor and tracking their response. Alternatively, their response to the experimental treatment can be recorded immediately after release under free-flying conditions.

Here, we make use of recent findings that weak anthropogenic electromagnetic noise disturbed the magnetic compass in a caged migratory songbird. Due to the low energy of the disturbance, it probably disrupts the operation of a radical-pair sensor by modifying its quantum spin dynamics, whereas it is unlikely to affect a magnetic-particle-based mechanism. This study aims to test for the first time whether anthropogenic electromagnetic noise disturbs the orientation ability of free-flying birds. For this, we specifically studied the potential effect of disrupting magnetoreception of temporarily caged wild migratory birds by exposing them to electromagnetic noise. If the birds' flight direction and/or the timing of their departure differ between experimental and control birds, this will favour the radical-pair mechanism as the mechanism responsible for perceiving magnetic compass information.

For this study, we have specifically selected one nocturnal songbird migrant, the northern wheatears (Oenanthe oenanthe), because it is well suited for orientation/navigation experiments and its flight and migration behaviour is well studied. During migration, northern wheatears, like most songbird migrants, alternate bouts of travel with stopover periods that serve to rest and to accumulate energy stores. At each stopover, the individuals decide daily when to resume migration (day-to-day departure decision). When the decision on departure has been made, two additional decisions must then be made as to when the departure should take place within the night and in which direction. Thus, the effect of the electromagnetic noise could potentially affect any of these three behavioural traits.

The study was conducted on the island of Helgoland in the North Sea (>50 km to the mainland), where the species is numerous during migration but do not breed. Northern wheatears were exposed to yes/no electromagnetic noise in cages and their immediate response after the release was radio-tracked by four digital radio-telemetry stations with twelve antennas that automatically record the bird's departure behaviour from Helgoland, i.e., time (day-to-day and within the night) and direction, at high resolution.

The results of this study will demonstrate i) whether the radical-pair mechanism is the main mechanism responsible for perceiving magnetic compass information in migratory birds and ii) whether anthropogenic electromagnetic noise has a biological significant effect on the global phenomenon of bird migration. If there is a long-lasting effect, e.g. delaying migration by a few days or more than 60 min within the night, or if experimental birds do not switch to use other compass systems for orientation in free-flight and thus show a larger circular variance than the control birds, this dramatically expands the area where birds are unable to travel towards their migratory destination. If so, electromagnetic noise has a significant global effect on the migration of birds worldwide.

A magnetic sense in bats? Evidence and knowledge gaps

Richard Holland | Bangor University, UK

Bats are the only mammals with powered flight and as such they can move over hundreds of kilometres during foraging and ranging flights. Alongside this there are migratory bats that move 1000s of kilometres between breeding and wintering sites. Because of this, bats make an ideal comparative model for studying navigation behaviour in a mammal, particularly as a comparison to birds, which face similar ecological challenges during migration. However, while it has been established for more than 50 years that birds have a magnetic sense, bats, and mammals in general, lag far behind, with evidence for a magnetic sense only coming to light in the last 15 years. The volume of research on bat navigation, particularly during migration, has lagged behind because their small size and nocturnal behaviour makes them difficult to study, and until recently there has been no correlate of migratory behaviour similar to the migratory restlessness shown by birds. In this talk I present the evidence for a magnetic sense in bats, that has started to be gathered since its first demonstration in 2006. In keeping with other mammals studied, the evidence suggests that the magnetic compass sense in bats may operate on different principles to that of birds, with polarity rather than inclination as the key physical parameter of the magnetic field being used. Tests that are argued to be diagnostic of a magnetic particle based magnetic sense support the presence of this system in bats, and new evidence suggests their response is different to that of birds, again hinting at a different mechanism for compass use in bats. Thus, to date there is no evidence that bats have a radical pair compass which is implicated in the effect of RF fields on orientation in songbirds.

Alongside evidence that bats use the magnetic field as a compass, several experiments have indicated that the magnetic compass is calibrated at sunset, although homing and migratory bats appear to use different aspects: polarized light in homing, the suns disk itself in migration. Thus, when considering the possible effects of EMF on bats, time of exposure should be taken into account. To date the effect of RF noise in the same range as that which disrupts birds has not been tested on bats, but given the apparent differences in the magnetic sensory mechanism, bats should possibly be considered a test for more general effects of such noise on behaviour or cognition. One study has tested the effect of radar signals in the 1-4 GHz range and found a significant reduction in bat activity when field strength was >2v/m. Bats appear to avoid areas with EMF in the GHz range, therefore. There is, however, no known interaction with the radical pair magnetic sense at this frequency and so an effect on the magnetic sense is not thought to be a functional explanation of this phenomenon.

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Magnetoreception in Mammals

Pascal Malkemper | Max-Planck Institute, Germany

Magnetoreception, the ability to sense the Earth's magnetic field, is widespread in the animal kingdom. There is plenty of behavioural evidence that birds, turtles and amphibians use a magnetic compass for orientation, but while the impressive navigational abilities of mammals are evident, the role of a magnetic compass is less clear. In this talk, I summarize the current knowledge on the magnetic sense of mammals and make the point that if we want accurate estimates of the effects of anthropogenic magnetic fields, we need a deeper understanding of the mechanisms underlying mammalian magnetoreception. The talk consists of three parts.

First, I will give an overview of the mammalian taxa that appear to have a magnetic sense. For most of these taxa, the evidence bases on field observations of magnetic alignment, which is a preference of animals to align their body axis with the field lines of the Earth's magnetic field. While these observations have the heuristic potential to extend the list of magneto-sensitive mammal species, the evidence is purely correlative and yields only limited insights into the properties and mechanisms of the magnetic sense.

In the second part of my talk, I will turn towards studies on rodents. These have provided strong evidence for a magnetic sense in several rodent species, as they have been performed in the laboratory, ensuring proper control of magnetic stimuli and other confounding factors. While the data also contributed to a basic characterisation of the involved mechanisms, it needs to be highlighted that the cellular and molecular basis of magnetoreception remains a mystery – not only in mammals. Two main mechanisms are currently discussed: A magnetic particle-based mechanism (MPM) and a chemical compass based on light-induced radical pairs (RPM). In rodents, similar to birds, evidence supporting both mechanisms exists. It is unclear, however, if the mechanisms serve different tasks, complementing each other in the same species, or whether they are a consequence of ecological differences between species. Current data suggest that epigeic mammals with well-developed eyes use an RPM, while mammals with reduced eyes such as mole-rats and bats make use of a light-independent MPM. Importantly, the effects of anthropogenic fields on the magnetic sense differ between the mechanisms.

In the last part of the talk, I will present the philosophy and some data of my laboratory. Our aim is the identification of mammalian magnetoreceptors by a neurobiological approach, using African mole-rats as an animal model. In one line of research, we employ whole brain neural activity screens with tissue clearing techniques to map all brain areas involved in magnetic orientation. Knowledge about the brain areas involved in magnetic orientation will help us identifying the tissue that harbours the primary magnetosensory cells. We then utilize a variety of modern imaging techniques such as light sheet microscopy, high-resolution MRI, synchrotron-based X-ray fluorescence, and nitrogen valence magnetic imaging to find magnetoreceptive structures in these tissues.

Effects of electromagnetic fields on dairy cows

Michael Hässig | University of Zurich, Switzerland

The effect of electromagnetic fields associated with mobile telephones on the health of human beings and animals is still controversial discussed.

We are surrounded by numerous electromagnetic fields of variable strength, coming from electronic equipment and its power cords, from high-voltage power lines and from antennas for radio, television and mobile communication. Particularly the latter causes controversy, as everyone likes to have good mobile reception at anytime and anywhere, whereas nobody wants to have such a base station antenna in their proximity. As to newer knowledge humans are more exposed to cellular phone than to base stations. In animals this can be different. Each new generation of cellular phone communication takes advantage of higher frequencies for higher information transfer. The changes of technical generations have an average of 3 to 5 years, whereas profound clinical studies take about 10 years to proof harmlessness evidently. Actually, the focus by the responsible state offices is lead to heat or energy absorbed by humans and animals, giving threshold values for regulations, whereas the focus on athermic biological interactions of NIR with organs and resonance phenomena are seldom implemented in decision finding.

In a first study back in 2000, we examined and monitored a dairy farm in which a large number of calves were born with nuclear cataracts after a mobile phone base station had been erected in the vicinity of the barn. Method of choice for diagnosis of nuclear cataracts is slit lamp biomicroscopy. Sensitivity of histology for nuclear cataracts is low (62%). Calves showed a 10 times higher risk for heavy cataract if born there compared to Swiss average. All usual causes such as infection or poisoning, common in Switzerland, could be excluded. Even with positive temporality, the real cause of the increased incidence of cataracts remains unknown.

In a second study, we evaluated the prevalence and etiology of nuclear cataract in Swiss slaughter calves. 253 freshly slaughtered calves were examined by slit lamp biomicroscopy. Lenses with cataracts were examined histological. The activity of glutathione peroxidase, catalase and superoxide dismutase was measured in aqueous humor of each eye. All calves were tested for BVD, Neospora caninum and Toxoplasma gondii. Since each calf in Switzerland is identified by an ear-tag, the complete pedigree was obtained. The correlation between congenital cataracts and the effects of non-ionizing radiation from mobile phone base stations was evaluated. Therefor the data of all Swiss base stations, concerning location, field strength, direction of transmitting, were obtained from the federal office for communication. 81 (32%) of the 253 calves showed nuclear cataracts of variable severity. Dense nuclear cataracts were seen in 9 calves (3.6%). None of the affected calves tested positive for BVD, Neospora caninum or T. gondii. Inherited cataracts could be ruled out based on pedigree analyses. More male calves were affected. Histology revealed signs of cataract in 62 of 100 lenses. The activity of glutathione peroxidase was significantly general linear model) association of strength of base stations at the location of the calve just before slathering with nuclear cataracts was shown to start in the first trimester of gestation. The prevalence of congenital nuclear cataracts in slaughter calves in Switzerland is relatively high. The statistically significant decreased activity of glutathione peroxidase in eyes with cataract suggests that these eyes were under oxidative stress. It appears that during organogenesis the risk for the development of nuclear cataracts in calves is associated with radiation of mobile telephone antenna base station.

The purpose of the third study was to determine the association of mobile phone base stations (MPBS) with the activity of the antioxidant enzymes GSH (glutathione peroxidase), SOD (superoxide dismutase) and catalase in aqueous humor of veal calves as indicators for oxidative stress in veal calves exposed to MPBS. A cross sectional study of 253 calves was conducted to evaluate the redox status by measuring the activity of GSH, SOD and catalase in aqueous humor of the eye. Follow-ups were performed to assess the geographical location of each calf and its respective nearest MPBS by means of field strength and distance, and all MPBS within a range of 10 km by means of total field strength. The general linear model was significant to the field strength of the nearest MPBS (p = 0.042) and to all MPBS within a radius of 10 km (p = 0.042) concerning ln (Catalase) (logarithm naturalis of Catalse), but showed no tendency to the distance of the nearest MPBS. There was a tendency between ln(GSH) and the distance to the nearest MPBS (p = 0.072), the field strength of the nearest MPBS (p = 0.120) and the field strength of all MPBS within a 10 km radius The SOD activity failed to show a tendency related to the distance of the nearest MPBS, but was significant to the field strength of the nearest MPBS (p = 0.036). The SOD activity showed a tendency for a relation for field strength to all MPBS within a radius of 10 km (p = 0.057). This study suggests an influence of MPBS on the redox status of aqueous humor in veal calves and might be related to oxidative stress. In this experiment, the NIR has resulted in changes in the enzyme activities. Certain enzymes were disabled, others enabled by NIR. Furthermore, individual behavior patterns were observed. While certain cows reacted to NIR, others did not react at all, or even inversely.

In a fourth study, a controlled case-control study where the cases served sequentially as their own control was performed. The non-ionizing radiation (NIR) exposure equipment was provided by IT'IS Foundation of ETH Zurich (Eidgenössische Technische Hochschule; Federal Institute of Technology). The exposure was from three 900 MHz-antennas (SPA 920/65/9/0/V, Huber & Suhner, Herisau, Switzerland) installed at 2 m height behind the ten cows with a 30° downward tilt and not reachable either by the cows or staff. The signal was similar to a GSM base station, with 5 GSM (voice) and 3 EDGE - (data) pulses within each of the 4.62 ms repetitive GSM frames. One of the GSM-pulses used was 3 dB higher, to simulate the control pulse. While the EDGE pulses show amplitude variation, due to the 8 PSK modulation used. In total, a peak-to-average ratio of 2.2 (3.4 dB) resulted. The Federal Office of Communication (BACOM) allocated an experimental license defining the carrier frequency of 916.5 MHz and the maximum effective radiated power, which in turn defined the maximum field strength available at the cow locations. The field strength was measured in the empty stalls where the ten cows would be located. Between 10 to 14 days prior to the exposure to radiation, ten blood samples, one per day from the tail vein of each cow were taken to obtain control values of enzyme activities (pre exposure phase). After this, the transmitter was active for 4 weeks. The first 14 days were selected as the adaptation phase followed by a 14-day test phase (exposure), during which again 10 blood samples were taken from each cow again. Then, the system was turned off. The cows had a 14-day break before one last time within 14 days 10 blood samples were taken (post exposure period). To compare the individual enzyme values directly, a Rf-transformation or standardization was made with the range as 100 units for each parameter. Summarizing the findings of individual cows, the combined Rf-values of catalase, GSH and the inverse SOD increased between pre-exposure and exposure and declined between exposure and post-exposure. It shows a controversial situation that there are NIR-sensitive, as well as NIR-non-sensitive cows. Cows representing the majority of a certain time course over the three phases were referred to as reagent (4 cows out of 10). Cows representing an alternative time course over the three phases were referred as inverse reagents (one cow). Those without response to NIR were referred to as non-reagents (3 cows). The present results coincide with the information from the literature that NIR will lead to changes in redox proteins and that there are radiation-sensitive, as well as non-radiation-sensitive individuals.

The study approach with 10 blood samples per cow and phase (pre-exposure, exposure and post-exposure) has proved appropriate. To make a higher reliable statement regarding NIR reactivity, more animals should be tested. The present results coincide with the information from the literature, according to which NIR leads to changes in redox proteins, and that there are individuals which are sensitive to radiation and others that are not. However, the latter could not be distinctly attributed – there are cows that react clearly with one enzyme while they do not react with another enzyme at all, or even the inverse. The study approach of testing ten cows each ten times during three phases has proven to be appropriate.

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Session 3.3: Effects of electric and magnetic fields on invertebrates

Electrosensitivity and electric ecology in insects

Daniel Robert | University of Bristol, UK

Working together to exchange nutrition for pollination services, bees and flowers interact relying on vision, olfaction, touch, and humidity sensing. Recently, we have discovered that bees can also detect and learn about the weak electric field that arises as they approach a flower. This electric field is generated because flying bees are usually electrically positively charged whilst flowers tend to be negatively charged. A third component contributes to this electric interaction, the atmospheric potential gradient (APG) that is a consequence of the ionization of the atmosphere and the global electric circuit. I will present our current understanding of this triadic interaction (Bee-flower-APG), but also specifically discuss the role that triboelectrification may play in the sensory ecology of terrestrial arthropods and plants. It will be shown that physical contact and friction between insects and their environment can generate charge separation and a Coulomb force. It will be proposed that this triboelectric charging may play a role in the biology, and sensory ecology, of plants and insects. The enticing possibility that many arthropod species, beyond bees, are capable of electroreception will be proposed and discussed.

Social communication in the honeybee colony with temporal electrostatic field patterns

Benjamin Paffhausen | Freie Universität Berlin, Germany

The honeybee (Apis mellifera) is of great ecological and economic importance. This eusocial insect plays a major role in pollinating plants and shares similar ecological niches with many flying insects that are not under tight human control like the honeybees. From a behavioral and neuroscientific perspective, the honeybee is an intensively studied model organism topics related to social communication inside the hive. Foraging bees charge up their exoskeleton while flying. When they perform their ritualized movements during dance communication the emanating temporally modulated electrostatic fields are highly informative. These electrostatic charges are a candidate modality for the dance information receiving bees. Honeybees have been shown to learn electrostatic fields and they use the Johnston organ as a sensor for it. Therefore, we developed a new method to record electrostatic charges in a mostly undisturbed hive. These electric signals contain signatures of different types of dances, stop signals, buzzing, whooping and others. These different signals can be differentiated by their frequency components and duration. The amount and proportion of these social signals and their intrinsic properties are investigated to find correlates with external factors that might disturb the hives wellbeing. These factors include diseases, parasites and pesticides. To tightly control for external factors that influence the social communication in a natural manner like weather conditions and food supplies, data is also collect about the hives inside and outside temperature and humidity as well as its weight and the bee activity at the entrance. This multi-dimensional data, gathered from several hives scattered all across of Germany, is analyzed towards correlations of social signals and the colonies health. Preliminary data shows changes in the amount of dances when hives are treated with pesticides. It is also evident that pesticides change the proportion of certain frequencies that make up the dance signal. One of our main focuses is to find predictors for undesired and harmful situations. Predicting swarming, pesticide damage and diseases would raise this device, used for questions of basic science, to a powerful tool for apiarists and agriculture.

Insect circadian rhythm responds to weak radiofrequency field

Martin Vácha | Masaryk University, Czech Republic

Man-made radiofrequency (RF) electromagnetic fields have been shown to have effects on animal compass orientation at remarkably weak intensities but have until now been considered to be linked to orientation of migratory animals. Here, we tested if weak RF fields also affect the circadian rhythm of the German cockroach. We observed that static MFs slow down the cockroach clock rhythm, consistent with results on the Drosophila circadian clock. Remarkably, three hundred times weaker RF fields likewise slowed down the cockroach clock. This demonstrates that the internal clock, a ubiquitous feature of many animals can be sensitive to weak RF fields, consequently opening the possibility of an influence of man-made RF fields on many clock-dependent events in living systems.

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The effect of magnetic fields on plant growth development and evolution

Massimo Maffei | University of Turin, Italy

The geomagnetic field (GMF) is a natural component of our environment. Plants, which are known to sense different wavelengths of light, respond to gravity, react to touch and electrical signalling, cannot escape the effect of GMF. While phototropism, gravitropism, and tigmotropism have been thoroughly studied, the impact of GMF on plant growth and development is not well understood. The aim of the presentation is to provide an overview on the effect of GMF on plants.

Variations in magnetic field (MF) intensity are known to induce plant morphological and gene expression changes. In Arabidopsis thaliana Col-0, near-null magnetic field (NNMF, i.e., < 100 nT magnetic field) cause a delay in the transition to flowering. NNMF induced a delayed flowering time and a significant reduction of leaf area index and flowering stem length, with respect to controls under GMF. Generation experiments (F1- and F2-NNMF) showed a retention of flowering delay. In leaves and flowering meristem, NNMF caused an early downregulation of clock, photoperiod, gibberellin, and vernalization pathways and a later downregulation of TSF, AP1, and FLC. In the floral meristem, the downregulation of AP1, AGL24, FT, and FLC in early phases of floral development was accompanied by a downregulation of the gibberellin pathway. We evaluated the quantitative expression (qRT-PCR) of three clock genes (LHY, GI and PRR7) in time-course experiments under either continuous darkness (CD) or long days (LD) conditions in Arabidopsis thaliana seedlings exposed to GMF (~40 ↔T) and Near Null Magnetic Field (NNMF; ~40 nT) conditions. Under both LD and CD conditions, reduction of GMF to NNMF prompted a significant increase of the gene expression of LHY and PRR7, whereas an opposite trend was found for GI gene expression. Exposure of Arabidopsis to NNMF altered clock gene amplitude, regardless the presence of light, by reinforcing the morning loop. Our data are consistent with the existence of a plant magnetoreceptor that affects the Arabidopsis endogenous clock.

More recently, a time-course (from 10 min to 96 h) exposure of Arabidopsis to NNMF was shown to alter the content of some cations (NH_4^+, K^+, Ca^{2+} and Mg^{2+}) and anions (Cl^-, $SO_4^{=}$, NO_3^- and $PO_4^{=}$) as well as the expression of several cation and anion channel- and transporter-related genes as assessed by gene microarray. A few minutes after exposure to NNMF, Arabidopsis roots responded with a significant change in the content and gene expression of all nutrient ions under study, indicating the presence of a plant magnetoreceptor that responds immediately to MF variations by modulating channels, transporters and genes involved in mineral nutrition. The response of Arabidopsis to reduced MF was a general reduction of plant ion uptake and transport. Our data suggest the importance to understand the nature and function of the plant magnetoreceptor for future space programs involving plant growth in environments with a reduced MF.

Finally, one of the most stimulating observations in plant evolution is a correlation between the occurrence of GMF reversals (or excursions) and the moment of the radiation of Angiosperms. This led to the hypothesis that alterations in GMF polarity may play a role in plant evolution. We exposed Arabidopsis thaliana to artificially reversed GMF conditions. Our data show for the first time that reversing the GMF polarity had significant effects on plant growth and gene expression. This supports the hypothesis that GMF reversal contributes to inducing changes in plant development that might justify a higher selective pressure, eventually leading to plant evolution.

Role of cryptochromes in magnetoreception of plants and animals

Margaret Ahmad | Sorbonne University, France

It has been known for nearly sixty years that birds and other animals possess the ability to detect the magnetic field (MF) of the Earth and use it to obtain directional information. This ability appears to be widespread in many branches of the animal kingdom, from insects to birds, fishes, reptiles, and even a few species of mammals. More recently, the concept of MF detection has been enlarged to include any physiological or cellular process that can be altered by exposure to MFs, including circadian rhythm, behavioural and neuronal firing responses in flies; production of reactive oxygen species (ROS) in human cells; and finally many physiological responses in plants including seedling growth, stem and leaf development, flowering, and alterations in gene expression. Intriguingly, the underling magnetosensing mechanism for many of these responses involves an evolutionarily conserved blue light responding receptor known as 'cryptochrome', which has been implicated in magnetic field effects ranging from humans to plants.

This talk will first of all present evidence linking cryptochrome photoreceptors to magnetic field perception in plants, showing how even weak static fields of 10X earth field strength can alter plant growth, gene expression, and cryptochrome receptor activation under controlled conditions of illumination and temperature. Such magnetic sensitivity is thought to occur via the so-called 'radical pair mechanism', in which very weak (earth-strength) magnetic fields can interact with excited state reaction intermediates formed by biological receptors in the course of their activation. We will discuss in detail the structural and photochemical characteristics of plant cryptochromes that may mediate responsivity to static magnetic fields. We will conclude that, from the viewpoint of the plant, the perceived effect of exposure to MF is that a given blue light intensity will appear either 'brighter' or 'darker' in the presence of a MF. In other words, magnetic fields serve essentially to modulate, often only very subtly, the ongoing redox and photochemical reactions that are already occurring in the cell.

As further evidence that the radical pair magnetosensing mechanism is involved, we will present recent evidence that plant cryptochromes respond to RF (radiofrequency oscillating fields) in the MHz range, a feature of chemical magnetosensing that is predicted from the Radical Pair hypothesis and that has been extensively documented in birds. We will further extend our findings to assess whether cryptochrome activation by MF can explain certain MF responses in birds, flies, and human cell cultures by a conserved mechanism.

Finally, in the spirit of this workshop, we will summarize the impact of our findings with respect to possible environmental effects of EMFs, ranging from low level static fields to oscillating fields, RF and Wifi. Our conclusions are that although MF effects involving cryptochromes are 'real', they can only be demonstrated under highly controlled conditions and are vanishingly weak in comparison to effects of other environmental factors including pollution, light and ionizing radiation, and temperature extremes which induce stress in multiple organisms and adversely affect plant growth. It is nonetheless possible that, under long-term chronic exposure conditions, EMF may work synergistically with other environmental toxins or health 'risk factors' to induce cellular damage or disease related to oxidative stress in humans, or adversely affect growth in plants.

Human Magnetoreception: biophysical mechanisms and thresholds

Joseph L. Kirschvink, Connie X. Wang, Isaac A. Hilburn , Daw-An Wu , Yovan Badal and Shinsuke Shimojo | Caltech, USA

Although many migrating and homing organisms are sensitive to Earth's magnetic field as illustrated in the attached figure, most humans are not consciously aware of the geomagnetic stimuli that we encounter in everyday life. Either we have lost the magnetosensory system shared by many of our not-too-distant animal ancestors, or a system still exists with detectable neural activity but lacks potent output to elicit perceptual awareness in us. With initial support from the Human Frontiers Science Program, we now have strong support for the existence of a subconscious human magnetic sensory system [1]. We have found some brief, ecologically relevant rotations of Earth-strength magnetic fields that produce strong, specific, and repeatable decreases in EEG alpha band (8-13 Hz) power in the few seconds following magnetic stimulation. Similar brainwave changes are known to arise from visual, auditory, and tactile stimuli and are termed alpha event-related desynchronization (alpha-ERD). To date, our data show that: (1) the human geomagnetic compass response is polar in nature (can distinguish North from South), (2) can operate in total darkness, and (3) is not based on any form of electrical induction (and hence is not an electrical artifact). These results rule out both a free-radical quantum compass and an induction sensor as the transduction mechanisms, leaving a system based on biologically precipitated nanocrystals of magnetite (Fe_3O_4) as the most likely. The specificity of this human neural processing argues that this is an ancient sensory modality, which should share other known features of the animal geomagnetic sensory system including sensitivity to Rf and strong pulsed magnetic fields.

[1] C.X. Wang et al., 2019. Transduction of the Geomagnetic Field as Evidenced from Alpha-band Activity in the Human Brain.

Plant responses to high frequency electromagnetic fields: from gene expression to morphological changes

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In the past 15 years, we get interested to characterize plant responses to high frequency (900 MHz) electromagnetic field. We aimed to establish a formal and unequivocal link between the exposure and changes in plant metabolism. To keep things as simple as possible and to avoid contribution of external parameters to the experiment, we choose to expose plants for a short period (10 min) into a mode stirred reverberation chamber, that allows to generate a homogeneous and isotropic high frequency electromagnetic field. On the plant side, we choose to look at immediate responses (i.e. in gene expression and ATP synthesis). We demonstrated that a short (10 min) exposure to a low amplitude (5 V.m-1) high frequency (900 MHz) caused a rapid increase in the accumulation of several mRNA such as calmodulin, bZIP, CDPK, etc. These accumulations are rapid (15 min) and transient (about 1h) and of course do not show up in the control, non-exposed plants. We show that the same treatment caused a rapid drop in adenylate charge and that treatments with calcium counteracting drugs prevent the molecular responses. We also established that the response is systemic (i.e. it occurs in the whole plant if only part of it is exposed to EMF) and that abscisic acid is critical for the distant response in non-exposed tissues. However, we were unable to see any changes in the morphology of plants. This conclusion leads us to use rose plants in place of tomatoes to be able to follow plant development for a longer time (several weeks). Then we demonstrated that plant organs exposed to EMF are not affected in their development. In contrast, the meristems that were exposed lead to the production of shorter axes, demonstrating a delayed response. At present time, we are studying these delayed responses by exposing young germinating seeds of Arabidopsis using radiated ultrashort high amplitude electromagnetic pulses. We are following initial development and final ramification of plants. Initial results show that germinations initially grow faster, but then slow down and have on average fewer inflorescence axes than unexposed samples.

The influence of bioactive mobile telephony radiation at the level of a plant community – possible mechanisms and indicators of the effects

Marek Czerwinski | Poznań University of Life Sciences, Poland

Environmental exposure to radiofrequency electromagnetic fields (RF-EMFs) from mobile telephony has rapidly increased in the last two decades and this trend is expected to continue. The effects of this exposure at plant community level are unknown and difficult to assess in a scientifically appropriate manner. Such an assessment can be scientifically adequate if a studied plant community is completely new and control-impact radiation treatment is used.

In this review we aimed to predict ecological effects and identify indicators of the impact of bioactive RF-EMFs at the mobile telephony frequency range on plant communities. We considered the scenario where a plant community was exposed to radiation generated by a base transmitting station antenna mounted on a nearby mast. This plant community can be represented by mesic meadow, ruderal or arable weed community, or other herbaceous, moderately productive vegetation type. We concentrated primarily on radiation effects that can be recorded for a year since the exposure started. To predict them we used physical theories of radiowave propagation in vegetation and the knowledge on plants physiological responses to RF-EMF. Our indicators can be used for the detection of the impact of RF-EMFs on vegetation in a control-impact experiment.

The presentation will be based on the author's paper that has just been published online in journal Ecological Indicators:

[1] Czerwiński, M., Januszkiewicz, Ł., Vian, A., Lázaro, A., 2020. The influence of bioactive mobile telephony radiation at the level of a plant community – Possible mechanisms and indicators of the effects. Ecological Indicators 108, 105683. *https://doi.org/10.1016/j.ecolind.2019.105683*

Radiofrequency radiation injures trees around mobile phone base stations

Cornelia Waldmann-Selsam | Germany

In the last two decades, the deployment of phone masts around the world has taken place and, for many years, there has been a discussion in the scientific community about the possible environmental impact from mobile phone base stations. Trees have several advantages over animals as experimental subjects and the aim of this study was to verify whether there is a connection between unusual (generally unilateral) tree damage and radiofrequency exposure. To achieve this, a detailed long-term (2006-2015) field monitoring study was performed in the cities of Bamberg and Hallstadt (Germany). During monitoring, observations and photographic recordings of unusual or unexplainable tree damage were taken, alongside the measurement of electromagnetic radiation. In 2015 measurements of RF-EMF (Radiofrequency Electromagnetic Fields) were carried out. A polygon spanning both cities was chosen as the study site, where 144 measurements of the radiofrequency of electromagnetic fields were taken at a height of 1.5m in streets and parks at different locations. By interpolation of the 144 measurement points, we were able to compile an electromagnetic map of the power flux density in Bamberg and Hallstadt. We selected 60 damaged trees, in addition to 30 randomly selected trees and 30 trees in low radiation areas (n=120) in this polygon. The measurements of all trees revealed significant differences between the damaged side facing a phone mast and the opposite side, as well as differences between the exposed side of damaged trees and all other groups of trees in both sides. Thus, we found that side differences in measured values of power flux density corresponded to side differences in damage. The 30 selected trees in low radiation areas (no visual contact to any phone mast and power flux density under 50↔W/m (2)) showed no damage. Statistical analysis demonstrated that electromagnetic radiation from mobile phone masts is harmful for trees. These results are consistent with the fact that damage afflicted on trees by mobile phone towers usually start on one side, extending to the whole tree over time.

Addition October 2019

Between 2016 und 2019 the observation and photographic recording of several trees out of the study had been continued. The damages beginning on the exposed sides of trees increased year for year. At some trees only the half is left. Trees in low radiation areas however show furthermore no damage. Similar unilateral tree damages in line of sight to mobile phone base stations have been found in many German cities. Young trees do not grow well in the vicinity of mobile phone base stations. This development is very dangerous. Therefore, it is proposed that the 120 trees of this study will be reexamined by scientists in 2020.

Risk to pollinators from anthropogenic electro-magnetic radiation (EMR): evidence and knowledge gaps

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Worldwide urbanisation and use of mobile and wireless technologies (5G, Internet of Things) is leading to the proliferation of anthropogenic electromagnetic radiation (EMR) and campaigning voices continue to call for the risk to human health and wildlife to be recognised. Pollinators provide many benefits to nature and humankind but face multiple anthropogenic threats.

In this talk, we outline the values of and threats to pollinators. We then go onto assess whether artificial light at night (ALAN) and anthropogenic radiofrequency electromagnetic radiation (AREMR), such as used in wireless technologies or emitted from power lines, represent an additional and growing threat to pollinators.

This talk draws on an EKLIPSE foresight activity *(http://www.eklipse-mechanism.eu/)* and IPBES *(https://www.ipbes.net/)* evidence assessment protocols to assess the level of risk to pollinators from anthropogenic EMR, uncertainties and knowledge gaps. This involved a scientific literature search to gather a representative, but not exhaustive, set of relevant peer-reviewed papers published from 2000 onwards, coincident with the onset of the proliferation of mobile technologies. We scored studies according to their scientific and technical quality and we distilled key messages for scientists and decision-makers to evaluate our assessment of the published evidence and the level of the potential problem. To communicate the level of certainty in knowledge, we attached a degree of confidence to each key message using a qualitative 'four-box model' (following IPBES) that shows the assessment of the quantity, quality and level of expert consensus on the evidence.

Overall a lack of high-quality scientific studies means that knowledge of the risk to pollinators from anthropogenic EMR is either inconclusive, unresolved, or only partly established. A handful of studies provide evidence that ALAN can alter pollinator communities, pollination and fruit set. Laboratory experiments provide some, albeit variable, evidence that the honeybee Apis mellifera and other invertebrates can detect natural EMR, potentially using it for orientation or navigation, but they do not provide evidence that AREMR affects insect behaviour in ecosystems. Scientifically robust evidence of AREMR impacts on abundance or diversity of pollinators (or other invertebrates) are limited to a single study reporting positive and negative effects depending on the pollinator group and geographical location. Therefore, whether anthropogenic EMR (ALAN or AREMR) poses a significant threat to insect pollinators and the benefits they provide to ecosystems and humanity remains to be established.

Open access: *https://www.sciencedirect.com/science/article/pii/S0048969719337805*

Electromagnetic radiation of mobile telecommunication antennas affects the abundance and composition of wild pollinators

Amparo Lázaro, A. Chroni, T. Tscheulin, J. Devalez, C. Matsoukas and T. Petanidou | Mediterranean Institute for Advanced Studies, Spain

The exponential increase of mobile telephony has led to a pronounced increase in electromagnetic fields in the environment that may affect pollinator communities and threaten pollination as a key ecosystem service. Previous studies conducted on model species under laboratory conditions have shown negative effects of electromagnetic radiation (EMR) on reproductive success, development, and navigation of insects. However, the potential effects that widespread mobile telecommunication antennas have on wild pollinator communities outside the laboratory microcosm are still unknown. Here we studied the effects of EMR from telecommunication antennas on key wild pollinator groups (wild bees, hoverflies, bee flies, remaining flies, beetles, butterflies, and wasps). We measured EMR at 4 distances (50, 100, 200 and 400 m) from 10 antennas (5 on Limnos Island and 5 on Lesvos Island, eastern Mediterranean, Greece), and correlated EMR values with insect abundance and richness (the latter only for wild bees and hoverflies). All pollinator groups except butterflies were affected by EMR. In both islands, beetle, wasp, and hoverfly abundance decreased with EMR, whereas the abundance of underground-nesting wild bees and bee flies unexpectedly increased with EMR. The effect of EMR on the abundance of remaining flies differed between islands. With respect to species richness, EMR only tended to have a negative effect on hoverflies in Limnos. As EMR affected the abundance of several insect guilds negatively and changed the composition of wild pollinators in natural habitats, it might also have additional ecological and economic impacts on the maintenance of wild plant diversity, crop production and human welfare.

Ecological effects of electromagnetic fields on invertebrates

John F. B. Bolte, Martina G. Vijver, Tracy R. Evans, Wil L. M. Tamis, Willie J. G. M. Peijnenburg, C. J. M. Musters, and Geert R. de Snoo | The Hague University of Applied Sciences, The Netherlands

Most studies on biological endpoints lack in the consideration of potential effects which may directly affect other organisms or ecosystems. A review of 113 studies [1] showed ecologically relevant evidence that radiofrequency electromagnetic fields (RF-EMF) caused an effect in about 50% of the animal studies and about 90% of the plant studies. Therefore, we conducted a field study exploring relevant ecological endpoints at real-life exposure levels [2, 3].

AIM
Estimation of the impact of exposure to GSM base station signals (900 MHz) on different endpoints in the reproductive capacity of invertebrates.

FIELD
Four different hexapodae species, bugs, springtails, wasps and fruit flies, were placed at six locations in two containers: an exposed and a control group in a Faraday cage (Figure 1). The distance to the middle of the GSM 900MHz base station with two antennae was set in two transects, in order to have different exposure classes. The first transect was at 25m (A) and 62m (B) at 20 from north. The second transect was in the south-east direction, 170 at 16m (C), 73m (D), 143m (E) and 151m (F). The 48-hours electric field was measured by EME Spy 121 in the containers and double checked by Narda. The fields from other frequencies were below 0.02 V/m.

STATISTICS
Endpoint: Reproduction = classical ecotoxicological studies. Reproductive capacity of the exposed organisms was followed for 3 weeks in the laboratory. Exposure metrics are is power density and rate of change. Sensitivity differences among organisms were tested using univariate analysis with Bonferonni-correction to account for more than one toxicological endpoint per organism that are innerlinked

OUTCOME
The reproductive capacity of the hexapodae species was not affected by the short-term EMF exposure. For the particular levels of power density and rate of change metric as determined in our field no relationship could be found between exposure and responses. Hence, our null hypothesis that the reproductive capacity is not impacted by the EMF levels in the field could not be rejected. As the exposure to RF EMF is ubiquitous and is still increasing rapidly over large areas, we plea for more attention the possible impacts of EMF on biodiversity.

[1] Cucurachi S., Tamis W.L.M., Vijver M.G., Peijnenburg W.J.G.M., Bolte J.F.B., De Snoo, G.R., 2013. A review of the ecological effects of radio-frequency electromagnetic fields. Env. Internat. 51:116-140
[2] Bolte J, Eikelboom T, 2012. Personal radiofrequency electromagnetic field measurements in the Netherlands: exposure level and variability for everyday activities, times of day and types of area. Env. Internat 48:133-142
[3] Vijver M, Bolte J, Evans T, Tamis W, Peijnenburg W, Musters C, De Snoo G, 2014. Investigating short-term exposure to electromagnetic fields on reproductive capacity of invertebrates in the field situation. Electromagnetic biology and medicine 33(1):21-28. Posted online on June 19, 2013. (doi:10.3109/15368378.2013.783846).

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