Spotlight on EMF Research

Spotlight on “Upper bound for broadband radiofrequency field disruption of magnetic compass orientation in night-migratory songbirds” by Leberecht et al. in PNAS (2023)

Category [theory/molecular mechanism]

Spotlight - Mai/2024 no.1 (Eng)

Competence Centre Electromagnetic Fields (KEMF)

1 Putting the paper into context by the BfS

A plethora of migrating species are supported by some form of magnetic compass to orient themselves along the earth’s magnetic field (MF) on their journeys over thousands of kilometers. The most prominent candidate to explain this magnetic sense is the Radical Pair Mechanism (RPM) [2-5], in which two electrons in a pair of radicals form a joint quantum system whose state is magnetically sensitive. It is known from earlier experiments that some migratory songbirds’ magnetic compass can be disturbed by radiofrequency (RF) MFs [6,7]. The present paper [1] exploits this fact in order to gain insight into the molecular structure of the radicals involved in the RPM. For radiation protection, the RPM is conceptually interesting since it gives a biophysical model describing the interaction of weak MFs with chemical reactions.

2 Results and conclusions from the authors‘ perspective

According to the authors, the most likely candidate for a radical pair (RP) in the bird’s magnetic compass consists of a light-activated flavin adenine dinucleotide (FAD) and a protonated tryptophan (TrpH). The RP is denoted by [FAD●- TrpH●+]. The hyperfine structure, i.e. the energies of the spins of the electrons coupled to the surrounding nuclei, determines the resonance frequencies for which an external RF-MF can disturb the magneto-sensitivity of the RP. In particular, the difference between the highest and the lowest energy value determines a maximum frequency (the cutoff frequency) above which there should be no disruption of the compass. The cutoff frequency depends on the radical structure, e.g. if TrpH or some other radical accompanies FAD. In order to support the hypothesis of [FAD●- TrpH●+] being the radical pair involved, the authors performed behavioural tests on Eurasian blackcaps (Sylvia atricapilla) at broadband RF MF between 240 ± 5 MHz (slightly above the previously predicted maximum cutoff frequency) and at 145 ± 5 MHz (slightly above the lowest predicted cutoff frequency). The root-mean-square and peak field strengths were chosen in the same way as in [7], where magnetic compass disruption was observed at frequencies between 75 and 85 MHz. In both cases, birds were tested in normal geomagnetic field conditions and in a 120° horizontally rotated static MF direction. Both, RF-MF-exposed and control groups oriented themselves along the imposed static MF directions and no disruption of the magnetic compass was observed. As a consequence, the authors conclude that the cutoff frequency for this species lies even below the lowest predicted frequency of 140 MHz.

In order to extract information about the structure of the RP involved, the experimental study was accompanied by a computational part. The authors used the hyperfine structure of several RPs to compute the probability of exhibiting resonance effects triggered by external RF MFs, depending on the frequency. In "action spectrum histograms" (diagrams where the probability of a resonance effect is plotted against the frequency) the cutoff frequency is clearly visible and can be compared to experimental results. To keep computations tractable, the authors used models with a reduced number of nuclei in the environment of the RP. For the [FAD●- TrpH●+] RP, they observed resonances up to 99.3 MHz for a model without dipolar coupling (an electron-electron interaction) and a similar cutoff frequency. However, in a more realistic model they found very weak resonances, in sum less than 1% of the total amount of the resonances, up to 183.8 MHz. Finally, the authors estimate the cutoff frequency to be 116 MHz.

Combining the experimental finding of a cutoff frequency below 140 MHz with the theoretical prediction of a cutoff at around 116 MHz (based on the flavin RP), the authors conclude that a flavin-containing RP is the most likely mechanism for magnetoreception, in contrast to e.g. magnetic nanoparticles. For the latter, the corresponding frequency cutoffs would be orders of magnitude lower.

3 Comments by the BfS

This work is an important contribution to the search for a mechanistic explanation of avian magnetoreception. The authors use state-of-the-art spin dynamics calculations to predict cutoff frequencies in various candidate RPs. The inclusion of hyperfine structure data (calculated via density functional theory) for a considerable number of nuclei as well as dipolar coupling effects allows for a realistic modeling of the RPM. All data and code required to reproduce the paper are documented in the supplementary material [1] and a Git repository.

The presented experimental finding of a cutoff frequency below 145 MHz, together with earlier findings of a cutoff frequency above 85 MHz leave a narrow window for the maximal frequency that has to be predicted by a mechanistic model of the underlying effect. A flavin-based RPM fits well with a cutoff frequency in the expected window. The precise location of the cutoff frequency still depends on the details of the mechanism, but the presented results clearly support the RPM as an explanation for the avian magnetoreception. In contrast, other mechanistic models such as magnetite particles based on mechanic effects (like rotation or tumbling in an external RF field) do not predict similar sharp cutoff frequencies or do not hit the above frequency window.

To conclude, the present work provides further evidence for the RPM as the mechanistic explanation of avian magnetoreception. However, the results do not allow any conclusions about possible EMF effects on human health or the environment.

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Bundesamt für Strahlenschutz

Impressum

Bundesamt für Strahlenschutz
Postfach 10 01 49
38201 Salzgitter

Tel.: +49 30 18333-0
Fax: +49 30 18333-1885
E-Mail: spotlight@bfs.de
De-Mail: epost@bfs.de-mail.de

www.bfs.de

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urn:nbn:de:0221-2024050343640

Spotlight - Mai/2024 no.1 (Eng)