Magnetic orientation and radio-frequency oscillating electromagnetic fields: Possible mechanisms of interaction

Migratory birds are capable of navigating along flight paths for many thousand miles, performing complex orientation tasks that allow them to return to their point of origin. They accomplish this with brains weighing only a few grams and are aided by multiple physiological compass systems, such as sun, star, and magnetic compasses. The physiological basis of the magnetic compass remains unknown, but may involve magnetically sensitive electron spin processes in optically induced radical-pair chemical reactions. Such radical pair processes are expected to be affected by oscillating magnetic fields in a fashion comparable to standard magnetic resonance experiments. In a series of experiments with migratory birds [1,2], it was demonstrated that radio-frequency oscillating magnetic fields (ca 1-10 MHz) of about 1% of the geomagnetic field intensity disrupt magnetic orientation. A particularly strong resonance was observed at the free-electron Larmor frequency of ca. 1.4 MHz in a local magnetic field of 50μT intensity. At this frequency, oscillating fields of 0.1% of the geomagnetic field intensity were sufficient to disrupt magnetic orientation. Similar strong resonances at this frequency have been observed for non-migratory birds and cockroaches, suggesting the possibility of a common molecular basis for these effects. The fact that weak radio-frequency oscillating electromagnetic fields affect physiological orientation responses in a variety of organisms is of great relevance for the topic of this workshop, as it suggests a possible focal point of coupling electromagnetic fields to biological signal transduction. So far, the disruptive effects have been discussed in the framework of the radical pair mechanism and have been found to be largely consistent with effects on a long-lived radical pair reaction step [3]. However, there may be other mechanisms possibly including internal optical pumping that could also be consistent with the observed effects.

One key open question is whether one might be able to use artificial fields instead of the geomagnetic field to initiate rather than disrupt magnetic orientation responses. This is a considerably more challenging tasks as one needs to find artificial magnetic fields that nearly exactly reproduce the effect of the static field on the underlying magnetoreception mechanism. However, if successful, such experiments can provide much more reliable information about the mechanism of interaction between oscillating magnetic fields and the organism. Biomimetic man-made compass sensor devices based on radical-pair designs may be a necessary step towards understanding the biological system. Experimentally, several groups are engaged in moving from magnetic orientation studies with migratory birds to organisms amenable to molecular biological and genetic approaches, such as fruit flies or bacteria. Neurobiologists attempt to identify brain areas and neurons involved in magnetic information processing.

[1] Ritz, T. et al. Nature 429: 177 (2004).
[2] Ritz, T. et al. Biophysical J. 96: 3451 (2009).
[3] Ritz T. et al. J. Royal Society Interface 7:S135 (2010).