

SUPPLEMENTARY MATERIAL 2

Light-dependent magnetoreception in birds: The crucial step occurs in the dark

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2. Hypotheses on the mechanisms underlying the avian magnetic compass

Here, we give a brief summary of the hypotheses on the reception mechanisms providing birds with directional information from the magnetic field and their status concerning experimental support.

The avian magnetic compass has three typical characteristics: (1) it is an inclination compass not responding to the polarity of the magnetic field, but using the axis of the field lines and their inclination in space, (2) it has a fairly narrow biological window around the intensity of the ambient field, which is flexible, being able to adjust to other intensities, and (3) it requires short-wavelength light from UV to about 565 nm green (see [S1]).

The Radical Pair Model forwarded by Ritz and colleagues assuming that magnetic directional information is mediated by a radical pair mechanism, with cryptochrome, a photo-pigment with flavin adenine dinucleotide (FAD) as chromophore forming the radical pairs, is the only model so far that can explain these characteristics. The model with the experimental and histological evidence supporting it (references [1-18] in the main text) is briefly described in the Introduction of the paper. So far, all findings on magnetic compass orientation in birds are in agreement with this model.

Other mechanisms of magnetoreception, mainly based on magnetite, a ferromagnetic iron oxid, have been suggested, but there are conflicting findings. Superparamagnetic and single domain magnetite was described in the skin of the upper beak and the ethmoid region of birds (e.g.[S2-S6], but see [S7]); these receptors mediate magnetic information through the trigeminal nerve [S3;S8,S9]. However, this information does not seem to be part of the avian magnetic compass, because anaesthesia of the upper beak or disrupting the trigeminal nerve does not affect the compass orientation of migratory birds [S10-S12]). The latter also clearly speaks against a hypothesis suggesting integration of magnetite-based information and radical pair processes in providing compass information [S13]. Instead, the magnetite-based receptors seem to mediate information of magnetic intensity for navigation, as de-activating them or disrupting the trigeminal nerve suppresses navigational responses in migrants [S14] and removes the effect of a strong magnetic anomaly on the initial orientation of displaced homing pigeons [S15]. However, under certain light regimes when the avian magnetic compass is disrupted, migratory birds show so-called 'fixed direction responses', a behaviour that is different from the migratory orientation and does not change between spring and autumn. It seems to originate in the magnetite-based receptors, for anaesthetising the beak suppresses this behaviour, leading to disorientation [S16,S17]. For a review on these receptors, see [S18].

In 2011, Wu and Dickman reported electrophysiological responses in higher centres of the avian brain, which they assumed to originate in the lagena, part of the inner ear [S19]. Iron-rich particles were indeed found in the hair cells of the inner ear, but they are ferritin corpuscles not suitable for mediating magnetic information [S20,S21].- Information from the inner ear may be involved in the avian magnetic compass, but this is most likely information on gravity: as the radical pair processes are not sensitive for the polarity of the magnetic field; in order to distinguish between the two ends of the axis of the field lines, birds have to consider the inclination of the field lines, probably with the help of gravity [S22].

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