

Appendix 4 for J. Rabøl 2026: Reconsidering the goal area navigation hypothesis with special emphasis on juvenile night-migrating passerines and stellar navigation. – Dansk Orn. Foren. Tidsskr. 120: 15-28.

Experiments hypothesizing or claiming magnetic navigation

Own experiments and contributions

Rabøl (2014) tested 478 European chats and warblers on 29 nights in 2004-2005 and 2007, mostly long-distance African migrants and mostly Pied Flycatchers *Ficedula hypoleuca*, fewer medium-distance species, mostly European Robins *Erithacus rubecula*.

Control-birds were tested in the local magnetic field $+70^\circ$ inclination and $47 \mu\text{T}$ field intensity, The experiment birds were “displaced” in a southerly direction to $53^\circ/27 \mu\text{T}$, or in a northerly direction to $76.5^\circ/69 \mu\text{T}$ by subtracting (directed upwards) or adding (directed downwards) a vertical magnetic vector of the square of the local horizontal component of the Earth’s magnetic field. The coordinates calculated are not natural earthly combinations but supposed to be appropriate for the purpose. Considered in more details: the artificial magnetic field of mine could produce two different magnetic vectors: 1) $88.33 \mu\text{T}$ (twice the intensity of the local vertical magnetic vector), or 2) $21.43 \mu\text{T}$ (the square of the local horizontal magnetic vector). The purpose was to be able to invert the local field without changing the total magnetic intensity or deflect resultant mN towards mE or mW without changing the total magnetic intensity, accordingly.

The general procedure in 2004-2005 was: birds trapped as grounded migrants on Christiansø $55^\circ \text{N}/15^\circ \text{E}$ in the Baltic Sea and transported to Endelave $55^\circ \text{N}/10^\circ \text{E}$, where experiments were carried out. The birds were most of the time caged in the local magnetic field but two hours before sunset transported to the test-site and – then in the shifted magnetic field – exposed for the sun, sunset and later on the starry sky until 2 hours after sunset when transferred to the funnels for the next 1.5-2 hours under a starry sky. The single birds were used more than once shifting between controls and experimentals or vice versa. In 2007 the birds remained and were tested on Christiansø but only once, and first in the changed magnetic fields when transferred to the funnels exposed under the stars.

One may wonder why I exposed the birds for the stars, but even if the magnetic field is the primary one (as considered by most scientists) the stars may facilitate the course chosen through transference from the magnetic to the stellar compass, and in general stars on the sky is also known to increase both the migratory activity and the directional concentration thus facilitating the estimation/calculation of both the individual and sample mean vector.

The research hypothesis was that the controls should orient about SSW, and the northerly “displacements” maybe more S with a slightly higher sample concentration, whereas the southerly “displacements” should be oriented less concentrated NW-NNW. The general orientation was southerly in all three samples, i.e., the lack of northerly orientation in the S “displacements” was clearly jeopardizing the research hypothesis of a magnetic gradient navigation system in charge.

Rabøl (2014, appendix 2) presented and discussed 15 further magnetic cases, ten of which were concerned with birds and the last five with turtles, alligators, newts, spiny lobsters and salmons. All

these papers claimed influence of magnetic gradient navigation or at least presence of navigatory markers/signpost navigation. In my opinion, no clear cases of magnetic navigation were found. Obviously, homing pigeons seem able to use a magnetic navigator within their operational range of about 800 km around the loft, but in spite of many experiments all failed showing unambiguous confirmations of magnetic gradient navigation. Certainly, Procellariiformes with their extended foraging flights on the open sea seem even more probable candidates for magnetic navigation. However, attached bar magnets have no effect on their homing flights. Newts – active only within a few square kilometres area – seemed very unlikely candidates. Anyway, Phillips and colleagues managed to produce orientations indicative of navigation steered by magnetic inclination. However, the necessary short-distance displacements within and just outside the home area and measurements of the nearby magnetic field were not carried out. At least one year old turtles and spiny lobsters also looked promising but olfactory navigation (if navigation at all) appeared as better or at least just as good an explanation.

Swedish studies in passerine birds

Henshaw *et al.* (2010) tested the spring orientation of Lesser Whitethroats *Curruca curruca* trapped at Ottenby, Öland and displaced a little to the south of Stockholm. Here the birds were funnel-tested on the magnetic intensity and inclination conditions corresponding to a position in the Czech Republic and were significantly oriented towards N. Another sample was tested on the magnetic intensity/inclination of about Bodø, Norway. The orientation then shifted to random according to the authors ($r = 0.30$, $N = 27$, $z = 2.43$, $P = 0.08$). No mean direction was given, but on their fig. 2 it could be measured and also calculated to 322° . The authors concluded that the claimed random orientation was indicative that the breeding area of the “Bodø” birds was overshoot suggesting a magnetic navigation system behind the orientation. However, and at least as probable, the orientation at “Bodø” could be considered as compass orientation steered by the magnetic field in the same northerly direction as in the “Czech Republic”. This obvious possibility was not considered by the authors. Henshaw *et al.* refer to Fischer *et al.* (2003) about the simulated displacements of Tasmanian Silvereyes *Zosterops lateralis* (see Rabøl 2014) also concluding influence of magnetic navigation. However, as the way of treatment of the Silvereyes was not optimal the conclusion of Fischer *et al.* is not straightforward.

Without recording the migratory directions, several Swedish contributions were investigating the amount of activity, weight-changes, food intake and alike in caged passerine birds tested in changing magnetic fields. Rabøl (2014) discussed Fransson *et al.* (2001) and Boström *et al.* (2010, 2012). Later, several more papers were released such as Ilieva *et al.* (2018), and Bianco *et al.* (2019, 2022). All these papers bring the more or less hidden message that a magnetic navigational system was indicated. However, this is to carry the results too far. Certainly, the observation that the magnetic field is more or less influential on or coupled to some activities and fuelling patterns is not a proof and not even a strong indication that Earth magnetism is influential on migratory orientation and in particular it is not a signal about an influential migratory coordinate/gradient navigation system.

This distorted/unsecure view develops further in the next two sections.

Baleen whales

Horton *et al.* (2024) report on magnetic navigation in whales. The following is from the abstract: “baleen whale migratory destinations over the last >200 years are systematically distributed in horizontal plane magnetic coordinates”. Further, “Whales non-randomly inhabit areas of where magnetic declination (MD) closely approximates integer, or half-integer multiples of Earth’s 23.44° axial tilt”. Then: “Our findings ... demonstrate that baleen whale navigation between seasonal habitats occurs via the integration of magnetic and astronomic orientation cues”, and: “By referencing MD values to the rise and set azimuths of the sun, baleen whales movements define mechanistic horizontal plane heliomagnetic coordinate trajectories across all ocean basins”. The second and fourth citations refer to correlations which are considered as proofs of a navigation system involving the magnetic field of the Earth (shown in Horton *et al.* as figs 1, 2 and 4, respectively). For me it looks like the usual scenario: magnetic navigation is not directly demonstrated, but magnetism is involved or correlated in “some” way. Whether the core of this “something” has to do with a magnetic navigation system is not clear but of course possible.

Whales are aliens compared to migrant passerines. The same are glass eels considered in the next section. Anyway, blind accept of a magnetic navigation system in one kind of animals disperses easily to other kind of animals. In particular, in the present era, where references to “known” examples of magnetic navigation are brought into attention and used to support a magnetic explanation of your own unclear results.

Glass eels

Glass eels *Anguilla anguilla* travel more or less passively across the Atlantic to Europe. Naisbett-Jones *et al.* (2017) report about glass eels collected in Severn Estuary, Southern Wales and their swimming directions recorded in laboratory in the local magnetic field (D), or – mimicking the magnetic inclination/intensity values – on three other magnetic positions: (A) the breeding area in the Sargasso Sea, (B) in the NW Atlantic E of Boston where the Gulf Stream moves NE, and (C) in the Atlantic ESE of Newfoundland, where the Gulf Stream moves ENE.

The swimming directions were recorded in twelve sections of 30° (0°, 30°, 60°, - - 330°) and a sample mean vector calculated and a mean direction shown if the sample concentration was considered significant. However, a Rayleigh test was not used for testing the significance. Instead, a Chi-square test (11 d.f.) was applied surely not appropriate for testing the significance of the mean direction but only for directional homogeneity. The orientation in C and D was claimed to be random.

The about SSW-orientation in A was significant. This direction seems peculiar but following such a direction from the Sargasso Sea the tiny leptocephalean larvae (the pre-stadium to the glass-eel) ends up in the Gulf Stream passing south of Sargasso and then bending towards NE and Europe. So, the SSW orientation makes sense and is appreciated by the authors. However, then the B-orientation is said to be significantly directed towards 60° confirming the expectation of an active swimming reinforcing the passive drift by the Gulf Stream. However, based on measurements on the circular distribution shown, I calculated a sample mean vector of 37° – 0.0296, which for N = 200 yields $z = 0.175$, i.e. the statistical significance for a directed movement is close to 0. The difference between

60° and 37° is insignificant and probably due to small measurement errors of mine. However, for me the B-distribution looks bimodal and doubling the angles leads to a significant bimodal sample mean vector of 80°/(260°) – 0.1252, $z = 3.14$, $P < 0.05$. Applying the Chi-square test of the authors leads to significance ($0.02 < P < 0.05$) i.e. confirms the authors conclusion but see above. Summing up, the orientation in B does not convincingly confirm the hypothesis of an active swimming enforcing the effects of the passive drift with the stream.

Next, the C-distribution is said to be non-oriented. However, this conclusion rests on use of the not appropriate Chi-square test. Using the Rayleigh test as in case of position B yields a sample mean vector of 205° – 0.1459, which for $N = 223$ and $z = 4.60$ yields $P = 0.01$, i.e. the SSW-orientation is clearly significant but in a rather opposite direction for an expectation of an active swimming reinforcing the passive drift by the stream. Finally, the D-distribution is random as also concluded by the authors and the interpretation of such a distribution could be several including that the glass eels reached their final destination.

Summing up, the evidence for use of the Earth's magnetic field is indeed weak. Perhaps, no one should wonder: is it at all possible to “displace” the memory of a glass eel long time back in time and expect meaningful reactions? In my mind, the conclusions in the Naisbett-Jones *et al.* (2017) paper could only be published in a leading scientific journal because the expectation and claim of magnetic navigation has been accepted as an established fact. In conclusion, “everything magnetic” is easily published and the field is open for all kind of flawed science, while stellar navigation, in contrast, is an almost forgotten concept which no-one dares to mention.

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Author's address: Jørgen Rabøl (jrabol@hotmail.com), Søndermølle 16, DK-8789 Endelave, Denmark