It is unclear whether infanticide provides such benefits to virgin male mice, given the fast weaning times and frequent oestrous cycles that are characteristic of this species. But aggressive behaviours spontaneously re-emerge in male mice 50 days after mating[6]: exactly the length of time it takes for their progeny to be born and weaned. Furthermore, exposure of a pregnant female to the scent of an unfamiliar male mouse is sufficient to cause termination of pregnancy[7]. As such, mice may be the champions of infanticide.

A picture is emerging in which regulatory nodes of social interactions switch on specific neural circuits at the expense of others[8,9]. These circuits underlie stereotyped behaviours, and coexist in both males and females, whether they are sexually experienced or not. But only under specific conditions are they activated. This is a remarkable example of the modularity and versatility of mammalian brains. ■

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SENSORY BIOLOGY

Radio waves zap the biomagnetic compass

Weak radio waves in the medium-wave band are sufficient to disrupt geomagnetic orientation in migratory birds, according to a particularly well-controlled study. But the underlying biophysics remains a puzzle. SEE LETTER P.353

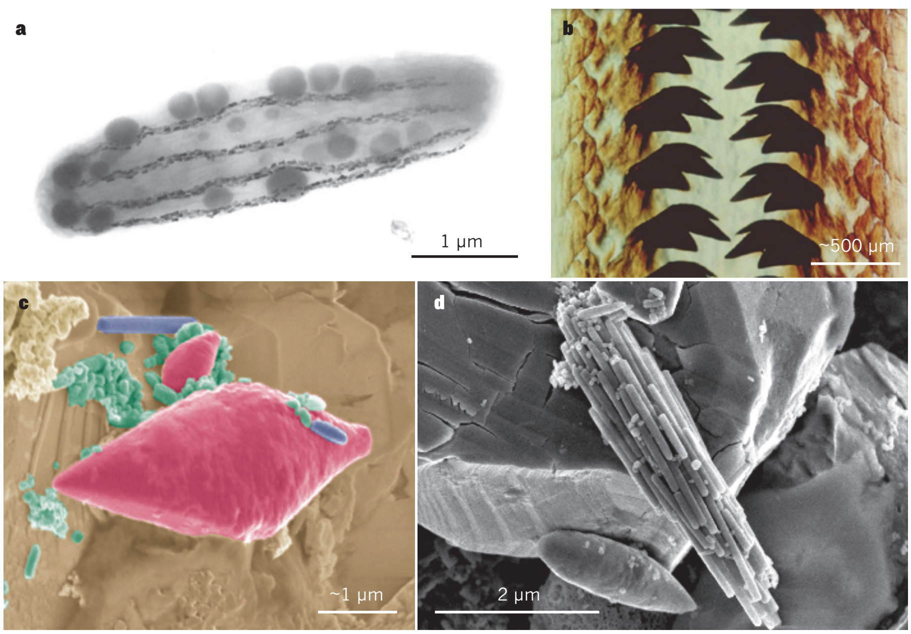
JOSEPH L. KIRSCHVINK

Magnetobiology has largely been viewed as a stamping ground for charlatans since the followers of physician Franz Anton Mesmer failed to cure patients using a 'magnetized' tree in the eighteenth century. Numerous discoveries have begun to change that perspective, although the road has been rocky. For example, early studies suggesting that migrating animals use geomagnetic cues for navigation were plagued by variability, but it is now clear that many microorganisms and animals use a magnetic compass for part of their orientation[1].

On the fringe of this fringe field were claims that radio-frequency radiation could have biological effects at levels too weak to act through the understood mechanisms of tissue heating or shock, but the experiments usually lacked proper controls and blinding techniques[2–4]. Now, however, on page 353 of this issue, Engels *et al.*[5] demonstrate convincingly that migrating European robins stop using their magnetic compasses in the presence of extraordinarily weak, radio-frequency electromagnetic 'noise'.

Using rigorous, double-blinded experiments, the authors found that birds housed in huts screened from background electromagnetic noise were able to use their magnetic compass to orient themselves appropriately, but that their orientation was disrupted following the introduction of electromagnetic noise ranging from 20 kilohertz to 5 megahertz, at intensities similar to that measured for background anthropogenic noise in the environment. To put it into perspective, this is in the medium-wave band used for AM radio transmissions (not, for example, mobile phones), and the strength is about equivalent to what a bird in flight might experience 5 kilometres away from a 50-kilowatt AM radio station.

Two results flag this study as particularly noteworthy, and puzzling. First, the levels of radio-frequency radiation that affected the birds' orientation are substantially below anything previously thought to be biophysically plausible, and far below levels recognized as affecting human health. Second, the authors detect no trace of a sharply enhanced effect at the Larmor frequency (the natural period at which single electrons wobble around the geomagnetic-field direction), which flatly contradicts experiments on the same species performed using a similar protocol[6]. This failure



A, MARIANNE HANZLIK; B, HEINZ A. LOWENSTAM/JOSEPH L. KIRSCHVINK; C,D, DIRK SCHUMANN

Figure 1 | Biological 'magnetomonsters'. Several fossil and extant organisms contain highly magnetic structures. Examples include: **a**, *Magnetobacter bavaricum*, a magnetotactic bacterium with nearly 100 times more magnetite in its cells than more typical types; **b**, *Cryptochiton stelleri*, a mollusc whose magnetite-capped radular teeth will stick strongly to a hand magnet; **c**, a spearhead-shaped magnetite particle (false-coloured red), prismatic magnetite rods (purple) and typical magnetite-containing bacterial organelles (magnetosomes; green); **d**, a bundle of magnetite rods forming 'wires'. The structures shown in **c** and **d** were extracted from fossilized clay sediments in New Jersey dating to approximately 56 million years ago[11]. The origins of the spearhead- and rod-shaped objects are not known, but their size and morphology suggest that they might have belonged to more-complex organisms. Cellular structures containing enough electrically conducting magnetite could be sensitive to radio-frequency radiation at levels shown by Engels *et al.*[5] to disrupt birds' geomagnetic orientation.

to replicate that effect perhaps underscores previously suggested[2,3] flaws in the blinding of earlier studies.

So what might be going on in these birds? Several other external stimuli that stop animals from responding to geomagnetic cues have been identified. Early studies of animal navigation noted that cues from the Sun or stars would take precedence over magnetic cues, leading to the idea that magnetism is the compass of last resort. It was then noticed that robins would ignore the magnetic field when the background intensity was shifted 20–30% outside the normal value[1], and that pigeons raced poorly during geomagnetic storms. From an evolutionary perspective, ignoring geomagnetic cues at such times makes sense, because anomalies in the background field are often associated with iron deposits or lightning strikes. Some animals also stop using their magnetic compass in the presence of red-only light, but such light is present only at sunrise and sunset, when the Sun compass is most reliable[3].

Hence, radio-frequency noise might be just another cue that tells migrating animals to ignore their magnetic sense, but the puzzle is why this might have evolved. Surprisingly, there is a natural source of the radio-frequency electromagnetic noise identified as disruptive by Engels and colleagues — that produced by solar storms. Coronal mass ejection (CME) events from the Sun slam plasma into Earth's magnetosphere every now and then, causing it to 'sing' at frequencies from as low as around 20 kHz up to the MHz range[7], some of which even leaks through Earth's normally radio-opaque ionosphere; the lower end of this range is remarkably close to that identified by the authors. These CME events generate the beautiful polar auroras, disrupt our use of the medium-wave radio band, and sometimes perturb the background geomagnetic field at Earth's surface enough to disturb animal navigation.

All known sensory systems in animals are based on cells specialized to convert the stimulus of interest into a coded stream of action potentials that are sent to the brain[8]. If the effects of radio-frequency radiation are real, such cells must exist, but the mystery is in the biophysics. The lack of an enhanced effect at the Larmor frequency, and the low levels of radiation concerned, make it unlikely that a previously proposed mechanism[6] for radiosensing, based on light activation of a cellular protein called cryptochrome, is involved. But some magnetic effects on animals (such as that of a short, sharp magnetic pulse[1]) function through biological magnetite (Fe_3O_4) in tissue — might this also be the radio-wave detector?

If it is, how could such a detection mechanism have arisen? Early animals that had a simple compass patterned along the lines of magnetotactic bacteria would have needed to survive geomagnetic excursions or reversals — periods in which Earth's magnetic field weakened — and natural selection would have favoured individuals with higher cellular volumes of magnetite[3,9]. When the field recovered, animals would have been left with cells that have surprisingly large magnetic moments[9] (Fig. 1). Such cells might then have evolved to serve other functions, such as intensity-based magnetic navigation systems, increasing the amount of magnetite further. With large enough volumes of metallically conductive magnetite in these cells, direct detection of the small electric and magnetic vectors of radio-frequency radiation might have emerged, as Engels and colleagues suggest.

Do the authors' findings have implications for humans? It seems that geomagnetic sensitivity dates back to an early ancestor of animals, and it is clearly present in many extant mammalian species. Human tissues also contain biological magnetite[10]. Many people claim to be bothered by radio transmissions, and some have even moved to live in radio-frequency 'quiet zones' around radio telescopes. Modern-day charlatans will undoubtedly seize on this study as an argument for banning the use of mobile phones, despite the different frequency bands involved. However, if the effect reported by the authors stands the acid test of reproducibility, we might consider gradually abandoning our use of this portion of the electromagnetic spectrum and implementing engineering approaches to minimize incidental low-frequency noise, to help migratory birds find their way. ■

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EVOLUTION

Geology and climate drive diversification

Data from the Galapagos Islands exemplify how geology and climate can interact to cause episodes of isolation and fusion of the biota across a landscape. Different scales of such cycles dictate varying mechanisms of species generation.

ROSEMARY G. GILLESPIE & GEORGE K. RODERICK

Writing in the *Journal of Biogeography*, Ali and Aitchison[1] examine geological and climatic events over the past 700,000 years, namely island ontogeny and shifting sea levels, and their effects on biodiversity in the Galapagos Islands. The authors propose a process that can be considered a general evolutionary mechanism: that the dynamics of isolation caused by geological and climatological processes plays a fundamental part in shaping diversity. Whether these processes promote or constrain species diversification, however, depends on the spatial (global, regional or local) and temporal (multimillion, multimillennial or multidecadal) scales and periodicity of isolation and coalescence.

Geological events have long been known to mould and shape biodiversity. A breakthrough in understanding the underlying mechanisms came with the recognition that ancient splitting of landmasses resulted in shared diversity. The concept of vicariance biogeography — the separation of a group of organisms by a geographical barrier — provided the means for rigorous hypothesis testing in a hitherto largely descriptive field. This established that vicariance resulting directly from geological events can cause diversification, such that geological history will be clearly reflected in the resulting biotic assemblages. The isolation created by ancient geological events is fundamental. Yet, what is given is frequently taken away — separate land masses can become connected and biotic assemblages reunited to various degrees. For example, the Great American