Sea Turtles: Navigating with Magnetism

Young sea turtles use the Earth's magnetic field as a source of navigational information during their epic transoceanic migrations and while homing. A new study using satellite telemetry has now demonstrated for the first time that adult turtles also navigate using the Earth's magnetic field.

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The ability of sea turtles to navigate across vast expanses of seemingly featureless ocean has long fascinated biologists. As hatchlings, turtles that have never before been in the ocean establish unerring courses toward the open sea and then maintain them after swimming beyond sight of land. Young juvenile turtles follow complex migratory pathways that often lead across entire ocean basins and back. Later, as adults, turtles migrate from feeding grounds to specific mating and nesting areas, after which many return to individual feeding sites. The itinerant lifestyle of sea turtles is thus inextricably linked to an ability to navigate through the open sea.

Studies with young sea turtles have suggested that a significant part of a turtle's navigational skill involves magnetoreception — the ability to detect the Earth's magnetic field. The Earth's field is one of several cues that guide newly hatched turtles as they migrate offshore for the first time [1]. Farther out to sea, magnetic fields unique to different geographic areas function as navigational markers that elicit changes in swimming direction at crucial points in the migratory route where the turtles might otherwise stray off course [1,2]. Older juveniles learn the magnetic topography of the area where they live and develop 'magnetic maps' which permit navigation toward specific target areas [3]. The large size of adults, however, has made the navigation of mature turtles difficult to study, and whether nesting females use mechanisms similar to those of younger turtles has been difficult to determine. A study published recently in *Current Biology* [4] has confirmed for the first time that adult turtles, like hatchlings and juveniles, use the Earth's magnetic field to guide their movements.

Scientific interest in sea turtle navigation began about fifty years ago with the writings and musings of the American zoologist Archie Carr, who was among the first to study sea turtles [5,6]. Carr, who died in 1987, lived to see many secrets of sea turtle biology revealed, but one that remained mysterious was how turtles navigate. Frustrated by the lack of progress in this area, Carr wrote near the end of his life that the lack of a credible theory to account for sea turtle navigation was "an insult to science" [7].

The honor of science was eventually redeemed when newly hatched loggerhead sea turtles were found to have a well-developed ability to sense the Earth's magnetic field [1,8]. Initial studies revealed that hatchlings have a magnetic compass sense, which enables them to maintain headings relative to the Earth's field as they migrate offshore [8]. In addition to providing directional information, the Earth's field also provides a potential source of positional information. The intensity (strength) of the field and the inclination or tilt of the field lines both vary predictably across the globe, so that each region of the ocean typically has a unique magnetic field associated with it [9]. Subsequent studies showed that hatchlings can detect both magnetic field intensity [10] and magnetic inclination angle [11]. Moreover, when exposed to regional magnetic fields that exist in widely separated locations along their migratory route, turtles that had never before been in the ocean responded by swimming in directions that would, in each case, facilitate movement along the migratory pathway [2,9].

The discovery that young turtles can distinguish among the 'magnetic signatures' of different oceanic regions led to the hypothesis that older turtles can use this ability to locate specific feeding and nesting sites [10,12]. The idea was that juvenile and adult turtles, as they gain experience with their habitat, might learn the magnetic topography of the areas where they live and eventually develop 'magnetic maps' that can be used in navigating to particular locations. The existence of such magnetic positioning systems was soon confirmed experimentally in juvenile green turtles (*Chelonia mydas*, Figure 1) [3].

Although much progress has been made toward understanding how hatchling and juvenile turtles guide themselves, navigational mechanisms and strategies in some species change as animals mature [13]. Determining whether adult and juvenile turtles navigate in similar ways has proven difficult, however, because adults weigh more than 100 kg and are much too large for the controlled laboratory experiments that have proven so powerful in unraveling the navigational mechanisms of younger turtles.

All of which brings us to the new study by Luschi *et al.* [4]. In an ambitious experiment, the authors captured adult female green turtles that had come ashore on a remote island in the Indian Ocean to lay their eggs. The turtles were taken by boat to locations 100–120 km away and released into the ocean with satellite transmitters attached to their carapaces, so that the paths of the turtles could be monitored as they returned to the island. Three groups of turtles were tested. Turtles in one group had magnets attached to their heads just prior to release. The magnets produced fields much stronger than that of the Earth and were intended to prevent the turtles from using magnetism as they swam back to the nesting beach. A second group of turtles had magnets attached to them during transport but removed prior to

release. The intent was to determine if strong fields applied during transport disrupted homing, either by preventing the turtles from sensing magnetic information as they were being carried to the release site or by producing a long-lasting effect on the magnetic receptors. Finally, a third group of turtles served as controls and had non-magnetic brass disks attached to their heads.

Luschi *et al.* [4] observed that the paths of turtles in all three groups were somewhat convoluted, but nearly all turtles eventually returned to the island. Oceanic currents presumably contributed to the indirect paths by constantly displacing the turtles from their attempted courses. When movements caused by currents were subtracted out, however, a clear pattern emerged: control turtles swam more directly toward the island than did either of the two groups of turtles that had been exposed to the magnets.

These results provide the first evidence that adult turtles use magnetic cues when homing to their nesting beaches. In addition, the study highlights the power of new techniques for analyzing the tracks of marine animals by resolving the paths into components attributable to ocean currents and those attributable to the animal itself [14]. Without this new approach, disentangling the effect of magnets from that of currents and other factors would have been difficult or impossible.

Although the magnets clearly affected homing, the exact part of the turtles' navigational system that was affected cannot be determined. One possibility is that the magnets disrupted a magnetic map sense like that known to exist in juvenile green turtles [3]. Alternatively or additionally, the effect might have been on a magnetic compass [8,15].

An unexpected finding was that magnets adversely affected navigation regardless of whether turtles were exposed to them while homing or only exposed during transport to the release site. Two interpretations of the latter finding are possible. One is that turtles can use their magnetic sense to derive some general information on the direction of displacement during transport. Alternatively, the application of strong magnets might produce an effect on magnetoreceptors that persists well beyond the time that the magnets are removed.

Figure 1. An adult green turtle on a tropical reef.
(Photo by Ursula Keuper-Bennett and Peter Bennett.)

The findings of the new study [4] may lead to a reconsideration of an earlier experiment in which magnets were attached to the heads of green turtles migrating to Brazil from Ascension Island, a small island in the south Atlantic [16]. Turtles leaving the island carrying magnets followed westward courses similar to those of control turtles, leading to the conclusion that magnets had no effect on open-sea navigation. An interesting caveat, however, is that satellite transmitters, which themselves produce magnetic fields and thus have the potential to disrupt magnetoreception, were placed on the heads of several control turtles. By contrast, all transmitters in the new study [4] were placed on the carapace and away from the head. If results of the earlier study are analyzed using only turtles with transmitters placed as in the new study, then a statistical difference exists between the latitudes at which the control and magnet groups reached the Brazilian coast [16]. Thus, with hindsight, the earlier study may also provide evidence consistent with the hypothesis that adult turtles exploit magnetic cues in navigation.

The results of both studies highlight an additional consideration: adult sea turtles, like all other animals studied to date, are likely to exploit multiple cues in navigation [7,9]. Although magnets impaired navigational performance in the new study and perhaps in the earlier one [16], the magnets did not, in either case, prevent the turtles from eventually reaching their goals. This implies that, when magnetic cues are disrupted, the turtles can fall back on other sources of information such as celestial compasses [17], wave direction [18], or olfactory cues [12], in much the same way that blind and blindfolded people are often able to use non-visual cues to guide themselves. Flexible use of multiple sources of information is likely in turtles, inasmuch as it occurs in homing pigeons [19] and in numerous other animals [20]. Regardless, however, the finding that adult sea turtles exploit magnetic cues in homing is a significant step forward in our understanding of these remarkable ocean navigators.

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