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Lohmann, K. J. (1992). How sea turtles navigate. *Scientific American*, 266, 100-106.

Taylor, G. J. (1994). The scientific legacy of Apollo. *Scientific American*, 271, 40-47.

Terborgh, J. (1992). Why American songbirds are vanishing. *Scientific American*, 266, 98-104.

Toumanen, E. (1993). Breaching the blood-brain barrier. *Scientific American*, 268, 80-84.

## HOW SEA TURTLES NAVIGATE

The newly hatched loggerhead sea turtles break through the sand covering their nest and scramble across the Florida beach to the ocean. They quickly set a course away from land and toward the open sea. After swimming day and night for anywhere from 30 to 50 miles, they reach the relative safety of the Gulf Stream. This is an impressive feat requiring oriented movement through a seemingly featureless ocean.

What are the various orientation cues that the hatchlings might use to guide their journey? Other migratory animals are known to rely on multiple cues such as the position of the sun or stars, odors, wind direction, low-frequency sounds, and the earth's magnetic field. It is one of the most pervasive and consistent sources of directional information available to animals. Unlike most other potential cues, the magnetic field is constant throughout the day and night and remains largely unaffected by weather changes.

To test whether turtles use magnetic field information to guide the direction of their swimming, an experiment was conducted in which the direction of the magnetic field was manipulated to be either in the northeast or in the southwest. When the field was in the northeast, they swam toward the northeast; when the field was in the southwest, they swam toward the southwest. The experiment demonstrated that the turtles used the magnetic field to orient their swimming.

Another cue that turtles might use to orient their swimming is wave direction. Swimming into the waves is a reasonable strategy for a hatchling searching for the open sea! An experiment was done to test whether turtles use waves to guide their swimming. Turtles were placed in a wave tank that was specially constructed of steel beams. The steel beams distorted the local magnetic field. This feature ensured that the magnetic field could not serve as an orienting cue for the turtles. The experiment demonstrated that turtles could use waves to guide the direction of their swimming. When there were no waves in the tank, the turtles swam aimlessly. However, when waves were generated, the turtles swam directly into the waves.

There is evidence from two laboratory experiments, then, that newborn turtles can use both magnetic field information and wave direction to orient themselves. But under natural conditions, do turtles use waves, the geomagnetic field, a combination of the two, or some completely different cue to guide their migration? These issues were examined by simply dropping hatchlings into the sea and recording the direction in which they swam. Under normal conditions, this procedure doesn't provide very useful information because wave direction and magnetic field provide the same orienting information.

Under what kinds of conditions would wave direction and magnetic field be at odds as orienting cues? Unusual weather (e.g., after a hurricane) can create wind conditions that cause them to move in directions other than from the ocean to the shore. When turtles are released into the water under such conditions, their behavior should reveal whether they use wave direction or magnetic field information to orient themselves. The experiment showed that turtles use wave direction as their primary orienting cue.

As remarkable as the orientation abilities of hatchlings seem, adult sea turtles are capable of more complex and sophisticated navigational feats. For instance, green turtles born on Ascension Island return as adults to the exact same beach every two to four years from their feeding grounds, 1,400 miles away. Adults could use wave direction to orient themselves on such a journey.

It seems very unlikely that wave direction could provide sufficient information to guide the trip. The turtles' other ability to detect magnetic fields is much better suited to determining position. Several geomagnetic parameters vary in predictable ways according to latitude, so magnetic field information might be used as a "map" to direct the turtles back to their birthplace.

At this point, however, we really don't know how the turtles manage this impressive feat.

Adapted from Lohmann, K. J. (1992). How sea turtles navigate. *Scientific American*, 266, 100-106.

## **DEVELOPMENT OF A THERAPY FOR MENINGITIS**

Few frustrations in medicine can match that of a doctor who holds a potent drug within inches of an infection it cannot reach. This frustration is rare for doctors treating an infection of the body, but all too common for neurologists treating an infection of the brain. The reason is the blood-brain barrier. The walls of blood vessels in the body are composed of loosely overlapping cells that allow many substances to flow into and out of them. In contrast, the walls of blood vessels in the brain are more tightly lined, allowing a few nutrients to permeate them while fending off most other substances.

This characteristic greatly reduces the chances of infection of brain tissues, but it also greatly increases the difficulty of treatment when an infection does occur. That is why bacterial meningitis is one of the biggest killers of adults and children worldwide. Until very recently, it killed up to one third of its victims. Of the survivors, more than half suffered brain damage leading to deafness or paralysis.

In meningitis's initial stages, there are no symptoms of infection because the bacteria themselves are not directly harmful to brain tissue. However, when the concentration of bacteria in the cerebrospinal fluid reaches 100,000 per milliliter, the body reacts by deploying hormone like substances called cytokines. The resulting swarm of white blood cells attacks the bacteria, but also results in inflammation, brain swelling and intracranial pressure that can cause seizures, coma, and death. It is actually the brain's frenzied defense in response to the presence of bacteria that leads to the symptoms and consequences of meningitis.

The mere suspicion of meningitis signals a medical emergency that leads the physician to immediately inject the patient with antibiotics. When antibiotics are given in very high doses, just enough will usually leak through it to kill most bacteria. Drugs of the penicillin family utterly destroy meningitis bacteria, but one of three children still dies.

How can penicillin kill the bacteria, yet many patients still die? The bacteria have a rigid cell wall that is maintained by enzymes that normally nip and tuck the wall into a perfect fit. Penicillin destroys the controls that restrain the enzymes, so that the bacteria's enzymes actually tear the cell wall to pieces. As the bacteria "explode" under the effects of the penicillin, the "shrapnel" is mistaken by the brain as a burst of bacterial growth. Recall that it is the level of concentration of bacteria in the cerebrospinal fluid that triggers the brain's defense mechanism. Thus, penicillin not only sometimes fails to cure the patient, it actually makes meningitis worse before it makes it better.

Alternative approaches to treatment might be more effective. One simple approach is to combine antibiotics to kill the bacteria with steroids to prevent the inflammation that causes brain damage in cases of meningitis. In fact, this treatment has worked so well that it has been adopted as recommended therapy for childhood meningitis. Unfortunately, steroids have significant side effects – such as gastrointestinal bleeding – that can be quite serious in a child already weakened by infection. So the current therapy should be viewed as a (very good) stopgap procedure until a better therapy is developed.

They are necessary only because of the side effects of penicillin. If the antibiotic treatment did not fragment the bacteria in the course of killing them, the self-destructive response of the brain's defense system should not occur and steroids would be unnecessary. A better antibiotic would be one that kills the bacteria while somehow masking the fragments to prevent the host defenses from recognizing them as foreign bodies.

What is the catch here? To deliver the antibodies into the brain, we still must find a way to pry open the blood-brain barrier. However, breaching the blood vessel walls would disturb the nerve cells of the brain which, in turn, might contribute to the injury seen in meningitis.

There is another strategy that might be used to treat meningitis. We might try to find an antibody that could keep white blood cells from entering the brain in the first place. There is an antibody, called anti-CD18, that is known to prevent white blood cells from sticking to the vessel wall. In theory, anti-CD18 should prevent white cells from crossing the blood-brain barrier for a few hours. In fact, anti-CD18 has produced a 100% survival rate in rabbits infected with meningitis. The antibody is currently being tested with humans and may one day be the standard treatment for meningitis.

Adapted from Toumanen, E. (1993). Breaching the blood-brain barrier. *Scientific American*, 268, 80-84.

## WHY AMERICAN SONGBIRDS ARE VANISHING

The steep declines in waterfowl, shoreline birds, and grassland birds over the past several decades are generally well understood. What is not as obvious is why forest-dwelling migratory songbirds are also vanishing; especially the so-called Neotropical migrants that breed in northern latitudes but migrate to winter homes in the tropics. As reports of decreases in songbird populations accumulated, it was widely noted that the missing species could still be found in large continuous tracts of forests, but not in isolated tracts. This observation was dubbed the "forest fragmentation effect."

What possible explanations might be given for the forest fragmentation effect? One simple hypothesis to explain the forest fragmentation effect is that they generally prefer larger forest plots as nesting sites and so avoid isolated plots because they tend to be small. This hypothesis predicts that the density of songbirds' nests in a forest will increase as the size of the forest increases. However, when researchers set about documenting the presence or absence of songbird species in forest fragments of different size, they obtained mixed and -- sometimes -- contradictory results.

Another hypothesis is that many songbirds are averse to the edges of forests and reject small, isolated tracts because none of the habitat is far enough away from the edges. There are good reasons why songbirds might want to nest away from the edge of a forest. Forest margins are brighter, warmer, drier and windier than the interior and support more shrubs, vines and weeds. This hypothesis was tested by observing the distribution of nesting territories in large forests that either surrounded a reservoir or had swaths cut to accommodate power-line rights-of-way. The results of the test proved that the hypothesis was wrong.

A third hypothesis derives from the observation that the species whose numbers have declined most drastically are the long-distance, Neotropical migrants. This hypothesis holds that tropical deforestation in South America (the winter home of the Neotropical migrants) is responsible for the declines, rather than fragmentation of the breeding habitat. The hypothesis predicts that declines should be greatest for species that winter in regions undergoing rapid deforestation and least for species that winter in relatively unscathed parts of the tropics. Comparisons of different species of Neotropical migrants do not support the hypothesis.

Two specific environmental changes have been identified that appear responsible for at least some of the decline in the songbird population. First, the suburbs are havens for nest predators such as blue jays, raccoons and opossums, so the dwindling numbers of them in isolated woodlots might be directly due to the activity of these animals. To test this hypothesis, one scientist placed quail eggs in artificial nests and set them out in small, medium and large forests, and -- for an undisturbed control site -- in the Great Smoky Mountains National Park. The results of the experiment confirmed the hypothesis.

The second factor responsible for the declining songbird population is an increase in nest parasites. Parasitic birds lay their eggs in the nests of other species, who often raise the resulting offspring as their own.

Why would this reduce the number of songbirds? A parasite's eggs typically hatch sooner than the eggs of its host, giving the hatchling parasite a head start over its nest mates. By the time the host's eggs hatch, the parasite is so much bigger than the host's hatchlings that it obtains most of the food brought by the parents and the host's own offspring often starve. A study in Wisconsin showed that 65 percent of the nests located near forest edges were parasitized by the cowbird. The accessibility of isolated forest tracts to nest predators and parasites explains why the songbird populations are declining in these areas.

We must also account for the fact that the Neotropical migratory songbirds have declined so much more quickly than other songbirds. In fact, it is not necessary to hypothesize a mechanism that selects the Neotropical birds out for special treatment because these migrants are naturally at a disadvantage in their breeding efforts. The Neotropicals have a shorter breeding season and lay fewer eggs than other species. Therefore, any environmental changes that reduce nesting success indiscriminately across all species would hit Neotropical migrants hardest because they have less margin for tolerance.

Adapted from Terborgh, J. (1992). Why American songbirds are vanishing. *Scientific American*, 266, 98-104.

## ORIGINS OF THE MOON

The Apollo spaceflights of the 1970s greatly advanced our understanding of both the moon and the earth, including the question of how our moon originated. Information gained from the Apollo program allowed us to reject several old theories and pointed out to an important new theory about the origins of the moon.

One classic theory of the moon's origins is the "capture hypothesis." You can guess the nature of this idea from its name. The theory holds that the earth's gravitational field seized a fully formed moon that came whizzing in from elsewhere in the solar system. In fact, the chances of the paths of two objects being just right for such a capture are miniscule, so the theory was not widely endorsed even before Apollo. Testing of lunar rocks brought back by Apollo put the theory completely to rest. It was shown that the moon rocks had quantities of oxygen isotopes similar to rocks on earth.

The second classic theory of the moon's origins, the "fission hypothesis," was proposed by George Darwin (the second son of Charles Darwin). He hypothesized that the earth was spinning extremely fast during a period after it formed a core. How could a fast rate of rotation of the earth create the moon? The spinning caused it to bulge so much at the equator that a small blob eventually spun off, becoming the moon.

This hypothesis can account for the fact that the moon is much less dense than the earth. However, the fission hypothesis claims that the moon was formed from material near the earth's surface. This means that the moon should have exactly the same chemical composition as the corresponding material on earth. Thus, the fission hypothesis cannot explain Apollo's finding that the earth and moon have different chemical compositions.

The third classic theory is the "double planet hypothesis", which states that the moon and the earth formed from the same cloud of gas and dust. The dust and gas gradually coalesced into the earth and a ring of material formed in orbit around the growing planet. The raw materials for the moon came from the ring.

The double planet hypothesis can explain some important observations. The theory can account for the similar composition of the earth and moon with respect to oxygen isotopes. However, the theory claims that the two bodies were formed from the same materials in the same fashion. Thus, the theory cannot explain why the moon's metallic core is so much smaller than that of the earth. The theory also does not explain the angular momentum problem; that is, why the earth rotates as fast as it does or how the supposed ring could have acquired enough circular motion to stay in orbit while the moon formed.

The failures of the classic theories of the moon's origins prompted astronomers to resurrect and develop a fourth theory, the "giant impact hypothesis." This hypothesis states that a very large object collided with the earth. The "impactor" caused debris to be thrown into orbit, which provided the raw material for the formation of the moon.

This theory does a much better job of explaining various facts that have posed problems for the classic theories. It explains that it lacks metallic iron at its core because the core of the object that collided with the earth stuck to the earth. Thus, the moon formed from the surface material of both the earth and the impactor. The similar isotopic composition of the earth and moon is because the earth and the impactor formed in the same region of the evolving solar system.

How does it explain the different chemical compositions of the moon and earth? The earth and the impactor were not formed of the same material, so they would be expected to have different chemical compositions. The different chemical composition of the earth and moon exists because the moon formed mostly from the impactor.

Most important, the impact hypothesis can explain the most difficult theoretical problem of why the earth rotates as fast as it does. A colliding body would probably not have struck the earth squarely; rather, it is highly likely that it would have struck the earth off-center. Such a blow would have acted like a basketball player's hand glancing off the side of the basketball to keep it spinning on his finger. This would speed up a slowly rotating earth to its current value of rotation.

Perhaps the most enticing aspect of the theory is that such a collision is a natural consequence of planet formation in that collisions of planetary bodies are actually not unlikely.

Adapted from Taylor, G. J. (1994). The scientific legacy of Apollo. *Scientific American*, 271, 40-47.