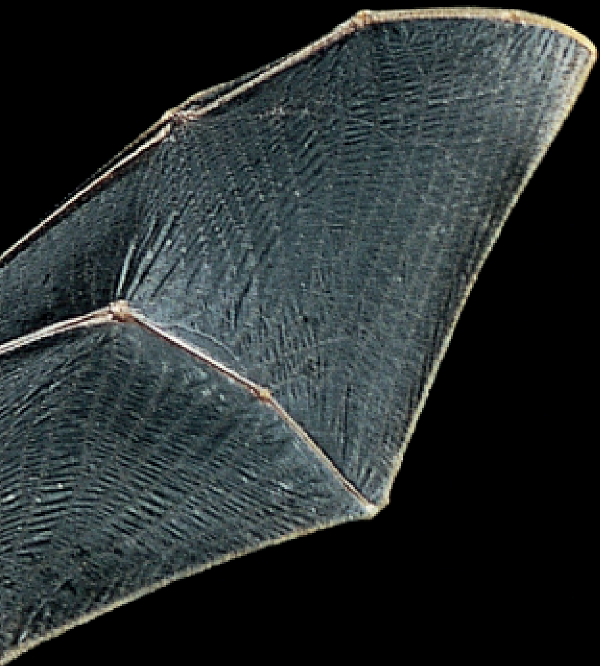
Bats use echolocation for foraging and orientation. Greater mouse-eared bats (*Myotis myotis*) locate insects in the grass by the noise they make while crawling.



On the Move with All Their Senses

As any child could tell you, bats see with their ears. **Björn Siemers** from the **Max Planck Institute for Ornithology** in Seewiesen and **Richard Holland** from the **Max Planck Institute for Ornithology** in Radolfzell have demonstrated that they also take their orientation from the Earth's magnetic field, calibrate their internal compass by the sunset – and may hold even more surprises in store for researchers.

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Photograph: Dietmar Nill

In a Helmholtz coil, two coils are placed parallel to each other on a common axis. Each individual coil has an inhomogeneous field. Due to the superimposition of the two fields, an area with a largely homogeneous magnetic field arises between the two coils near the coil axis. The magnetic field is freely accessible for experiments. Two bats have been placed in each of the coils shown here.

Vampires are pretty much unstoppable – a peril of which hardened fans of horror movies and stories have long been aware. Garlic provides only temporary help, and anyone aiming to drive a wooden peg into their undead hearts must first find the courage to get close enough to them. The arrival of the dawn is often the last hope because, if the myths are to be believed, vampires disintegrate into dust in sunlight. However, the human bloodsucker's supposed animal counterpart not only tolerates the sun's rays extremely well, it relies on them: bats adjust their internal compass with the help of the sunset. They can then orientate themselves using the Earth's magnetic field.

ECHOLOCATION ONLY WORKS AT SHORT RANGE

This ability of bats to calibrate their magnetic compass by the sun was discovered only recently. One possible reason why it took so long to demonstrate this is that researchers previously focused their attention on the flying mammal's unique main sensory skill: as has been known since the 1940s, bats use echolocation for hunting and orientation. In short, these animals see with their ears. They emit calls in the ultrasonic range, which is inaudible to humans, and listen for the returning echo. If the call hits an obstacle, for example a prey, it is reflected.

Bats can then derive important information from this echo. For example, the echo returns faster if the obstacle is close by. If the reflected sound is fainter at one ear than at the other, the bat can identify the direction in which the object is located.

However, echolocation only functions at short range. "Bats cannot use it to get a far-reaching overview of their three-dimensional environment," says Björn Siemers, head of a Max Planck Research Group at the MPI for Ornithology in Seewiesen: "They usually locate insects at a distance of just one to five meters. Because they fly at speeds of up to 35 kilometers per hour, for us, this would be more or less equivalent to travelling along a highway with a flashlight."

Nonetheless, some bats cover long distances in their search for food, around 20 or more kilometers every night. Distances in excess of 50 kilometers can also lie between their summer and winter roosts. In the case of some bat species that cover distances of over 1,000 kilometers, zoologists would go so far as to describe their behavior as migratory. Nathusius's pipistrelle bats, which are born in Poland, mate in Germany and winter in Holland, are a striking example of this phenomenon. "The question is how these animals find their way to the different locations," says Siemers. "It is difficult to imagine that the bats orient themselves over such distances solely by memorizing individual trees, bushes or other landmarks."

In his search for an answer to this question, the behavioral ecologist found an important pointer in the research carried out a few years earlier by his colleague Richard Holland as a Marie Curie Research Fellow at Princeton University in the US: "Up to now, research on how animals find their way in unknown areas was carried out primarily on migratory birds," explains

Photo: MPI for Ornithology – Björn Siemers

A greater mouse-eared bat (*Myotis myotis*) foraging. The animals produce calls in the ultrasound range that cannot be heard by humans, and then listen for the echo.

Photo: Dietmar Nill

Holland. “This research showed that these birds take direction from the Earth’s magnetic field. At some point it became clear to me that bats face similar challenges, so in collaboration with Martin Wikelski, I set out to determine whether they have a corresponding internal compass.”

Holland’s experiments appeared to confirm his suspicion. However, his experiments involved only a few animals and, as a result, his findings were received with a degree of skepticism – also on the part of Björn Siemers. The two researchers thus began testing for a possible magnetic sense in bats in the context of a larger study they carried out in Bulgaria. The bat colonies there are usually far bigger than those found in Germany. “If we catch and test a few specimens from thousands, it is less disruptive to the group than if there are only a few hundred animals altogether,” explains Siemers. After one or a few nights at the field station, the researchers release the bats again at the site of capture.

Together with their Bulgarian colleague Ivailo Borissov, Siemers and Holland aimed to initially establish whether bats can find the right direction in a place that is unknown to them and find their way home. It quickly emerged that this posed no problem for the greater mouse-eared bats. They were released in a harvested field around 25 kilometers away from their roost that provided the bats with very few clues for finding the correct orientation.

OUT AND ABOUT IN A REVERSED MAGNETIC WORLD

Using a radio transmitter attached to the back of the animal, the biologists were able to observe that most bats rapidly flew in the direction of their home caves after just a few kilometers: “The fastest animals needed only around two hours to get back to their roost,” says Siemers. “And I had had major doubts as to whether this test would even work.”

This did not, however, explain whether the bats took direction from the Earth’s magnetic field and adjusted their internal compass by the sunset. As was proven decades ago, this is precisely what migratory birds do. Researchers use devices known as Helmholtz coils to demonstrate this. The animals are exposed to an artificially generated magnetic field inside the coils, and the researchers can control the orientation of this magnetic field. Therefore, for the experiment in Bulgaria, the MPI scientists used Helmholtz coils to generate a rotated magnetic field for half of the animals, shifted from north to east by 90 degrees. The coils with the control bats were not switched on, so the natural magnetic field was accessible to these animals. One factor remained the same: all of the bats were placed under a transparent Plexiglas dome and were able to observe the sunset.

The animals in the control group found their way back to their cave immediately. However, the bats that emerged from the rotated magnetic world flew, in accordance with the artificial orientation generated in the coils, around 90 degrees in the wrong direction, to the east. “To test the effect of the sunset, we then repeated the experiment at night,” says Siemers. In this case, too, half of the animals


Photo: MPI for Ornithology – Stefan Greif

This cave in Bulgaria is used as a roosting location by different bat species. The image shows how the habitats of different species can overlap.

were exposed for one hour to a magnetic field that had been shifted from north to east. Any trace of the post-sunset glow had already disappeared by this time.

THE SUNSET POINTS THE WAY

All of the animals then flew directly to their home caves from the release site. "The manipulation of the magnetic field was thus effective only at sunset," comments Richard Holland, "because the magnetic compass is recalibrated on the basis of the position of the setting sun."

As a result, irrespective of whether the magnetic field tells them otherwise, west is where the sun goes down, as far as the bats are concerned. This is a good strategy, as iron deposits in the Earth's crust can cause fluctuations in the local magnetic field. The result is surprising, nonetheless, as nocturnal bats – and almost all of the 1,000-plus species that exist throughout the world belong to this group – would rarely get to see the sunset.

The mouse-eared bats start to fly only when the sun has long disappeared over the horizon. "An hour after the animals had flown out, we could still see from the brightness in the sky where the sun had disappeared to," says Björn Siemers. This glimmer of light is clearly sufficient for the bats to find their way.

But what happens on days with heavy cloud cover? "The animals probably stick to their last calibration," says Siemers. "We presume that they do not rely on daily calibration, but we will have to carry out more experiments to confirm it." It is also very likely that the bats note conspicuous landmarks and take direction from them, although this too, remains to be proven. "This is probably why the incorrectly calibrated animals from our magnetic field experiments noticed their mistake and found the right direction that would take them to their caves," speculates Siemers – despite the fact that the animals have rather poor eyesight. "Contrary to the common assumption, bats are not blind," stresses the biologist: "Their eyes are entirely capable of providing them with this kind of information."

Bats are an extremely successful group of animals that has produced numerous species over the course of evolution. In echolocation, they have a unique sensory system that they use primarily for orientation and foraging. Unlike birdsong and human speech, echolocation did not arise mainly as a means of communication.

YE SHALL KNOW THEM BY THEIR CALLS

Despite this, bats can recognize and differentiate other members of their species by their echolocation calls. As a project carried out by Siemers and his colleague Maike Schuchmann revealed, horseshoe bats also differentiate between echolocation calls from other species. This was even the case when their own frequencies overlapped with those of the tested animals.

These findings raise new questions: "We are not yet able to gauge the extent to which the animals actually make use of the capacity to identify other species on the basis of their calls," says Siemers. It would be conceivable, however, that they avoid superior competitors in their

Richard Holland (left) and Björn Siemers use an antenna to trace whether the bats, which have been fitted with miniature radio-transmitters and released into a harvested field, find their way back to their home cave. Holland is holding the receiver that picks up the signal.

foraging grounds in this way. It is also possible that they use this skill to follow other species with similar roosting requirements in their search for new roosting locations.

ADAPTED TO A VERY SPECIFIC NICHE

However, it may already be noted that, despite being just one of several senses – bats can see, smell, hear, and can also take orientation from the Earth's magnetic field – echolocation fulfils a wide range of functions. The researchers still must find out, however, how the animals perceive the magnetic field. As far as Björn Siemers is concerned, bats are without a doubt a perfect research object for sensory ecology: "I would like to better understand the role played by differences in sensory abilities for mediating resource partitioning in bat communities that share a habitat."

He suspects that differential sensory abilities will give the individual species access to different prey, and may thus reduce competition between them. In this way, even small differences could play an important role. A good example here are the bat species that forage for insects in the forest. This task is far from simple, as every irregularity in the tree bark, every blade of grass and every leaf reflects a bat's call. "The animals hear a lot of clutter echoes from the vegetation, in which a prey's reflection can be easily lost," says Siemers. In this situation, bats produce short, repeated calls. The frequency range and duration of the calls are adapted to the obstacle-rich environment, but are not identical in all species. For example, the Natterer's bat specializes in foraging directly at the vegetation edge. Its sonar calls can generate clearly recognizable echoes from insects against this background, and it can even locate a spider in its web. Other species in the same habitat are adapted to foraging between the trees, and may overlook the potential prey of the Natterer's bat as a result.

The greater mouse-eared bat, the largest bat species found in Germany, also recognizes its prey from the noise it makes and, initially, without using echolocation. As Björn Siemers has proven, the animals even fly toward the song of male bush crickets, who are aiming to attract females by singing, but may end up in the mouth of a bat instead.

It is known that this involuntary acoustic prey engages in its singing activities mainly from elevated locations so that it can be heard by females over a wide area. However, the male bush crickets also avoid very exposed locations. This may well be an adaptation to avoid exposure to their flying predators. The most important prey of the greater mouse-eared bat, the carabid beetle, also generally gives itself away by the rustling noises it makes on the ground.

Greater mouse-eared bats like to forage on dry ground or on mowed meadows because the beetles can hide easily in high grass. "We asked ourselves whether, perhaps, humans can also have a detrimental influence here," says Siemers. Two years earlier, the researchers succeeded in demonstrating that the bats avoid loud traffic noise: "Then we wanted to know what happens when they cannot avoid the acoustic disturbance."

The test involved the simulation of a highway roaring through the bats' customary foraging area. To do this, Siemers and his colleagues recorded highway traffic noise and played it back to the bats. "And, moreover, at a realistically high volume, which made it sound like trucks and cars driving past them close by," says the scientist. They also recorded the rustling sounds of carabid beetles in a sound chamber. The beetle rustling recording was

Photo: Stephan Eder – Geophysics, LMU

played at varying distances from the artificial traffic noise. The result: the closer the traffic noise, the longer the bats needed to locate the rustling sounds and the lower their foraging efficiency. However, even when the traffic recordings corresponded to a distance of just 7.5 meters from a road, the animals still succeeded in locating the beetle sounds half of the time. This proves that bats are extremely good at filtering out loud background noise. "These results highlight once again just how sensitive their hearing is," stresses Siemers. ◂

GLOSSARY

Ultrasound
Sound events above the human hearing range, between approximately 16 hertz and 20 kilohertz, are defined as ultrasound (1 hertz corresponds to one sound cycle per second). Most bat calls are very high frequency, typically above 20 kilohertz. Siemers and his colleagues succeeded in demonstrating the world record for a bat call of 250 kilohertz among Malaysian rainforest bats. Due to a phenomenon known as atmospheric attenuation, lower frequency sounds travel further than higher frequency sounds.

Echolocation
Despite its limited range, bats use ultrasound for echolocation because it provides relatively precise resolution. The physical principle at work here is that the higher the frequency, the smaller the wavelength and the smaller, again, the possible distance between two objects that still enables them to be reflected by two separate echoes. This means that they can be perceived by the bat as two distinct objects and not one (merged) object.

Vegetation edge
The edge structure of vegetation, for example of bushes or groups of trees.