Acoustic Innovation in the Dark Sky

For millions of years, bats have been making use of an acoustic detection technique that humans only discovered a hundred years ago. Human beings achieve innovations over months and years through intuition, persistent tinkering and, sometimes, also the luck of discoverers. The animal world, on the other hand, needs millions of years to create new biological solutions in the course of evolution.

1 The wings of the bat have developed from hands in the course of evolution.

The development of a terrestrial mammal into a flying nocturnal hunter — the bat — is remarkable. Early mammals, which were usually small, finally found that they had more space to live after the extinction of the dinosaurs 65 million years ago. However, the members of the rapidly growing mammal world soon competed against one another in a battle for terrestrial survival.

The air as a new habitat

A group of mammals became capable of active flight 50 million years ago: the bats. By evolving their hands into a wing-like structure (Fig. 1) — with a thin skin covering long fingers as the frame — bats were able to continue to hunt the insect species that had also escaped skywards in the meantime. But birds also hunted in the sky, and with their finely adjustable wings, they were far superior to the fluttering mammals. For the bats, the night sky provided a niche with less competition.

However, flying through a dark landscape and, in particular, catching insects in a lightless space required a completely new technology for object detection. How bats solved this problem remained a mystery for a long time. Yet as early as the year 1800, researchers knew that bats could somehow "see" with their ears.

Inventor of the sonar technology

But the English physiologist Hamilton Hartridge was the first to come up with the right idea in 1920. He suspected that, for millions of years, bats had been using a technique that the Royal Navy had just discovered: sound navigation and ranging (SONAR). The animals emit high-frequency sound signals and orient themselves based on the echoes (Fig. 2). The bat sends out a signal, and its brain is then able to calculate the distance to the obstacle from the time difference between the signal and the echo. In 1983, using ultrasonic microphones, the American professor of zoology Donald Griffin was finally able to provide proof of this technique, which he called echolocation.

The bats generate their locating sounds in their larynx and emit them through their nose or mouth. To focus the sounds optimally on the target, the bat's nose and mouth are shaped into bizarre megaphones, which give the animals faces that range from grotesque to demonic. The eight hundred bat species have developed a wide range of acoustic variants, depending on their habitat and their hunting techniques. The frequencies range from 160 kHz down to 15 kHz (15 000 vibrations a second). As a sound frequency of, for example, 80 kHz corresponds to a sound wave with a length of 4 mm, even small insects can still be "seen" with ultrasonics.

Better location thanks to faster signal sequences

When flying outdoors, the bat emits about a dozen ultrasonic signals a second. If the animal detects an echo, it quickly increases the sound sequence, because the more echoes per sound unit, the better the information. Once close to the object, the Little Brown bat chatters with its biosonar at 200 signals a second. The strength of the location sound also varies enormously.

2 Large ears as sound receivers.

Ultrasonics has the disadvantage that it is strongly muffled by the air. If a bat wants to detect an object dozens of meters in front of it, it really has to shout. The horseshoe bat, for example, which hunts small insects in wide open spaces, creates acoustic pressure in front of its mouth that exceeds 120 decibels. The equivalent in the human auditory range would be the noise of a pneumatic hammer. Species that hunt over short distances in dense forests, however, only need to whisper.

Biosonar performs phenomenally well. For example, bats can perceive distance differences of less than one centimeter, which equals an acoustic path of 0.06 milliseconds. They can locate tiny objects even more accurately. If you suspend nylon threads in a room, greater horseshoe bats will avoid these 0.08 mm thin threads without any problems.

Defense strategy of moths

In the course of evolution, however, many moths have developed defensive "bat warning devices": hearing organs with which they can hear the ultrasonic traffic in the most common range between 15 and 40 kHz. In this arms race, moustached bats, for example, have responded by emitting a quiet base sound for location at the same time as a very loud overtone. In this way, they can come much closer to their prey unnoticed.

However, the moths have added another defensive strategy. Their body hair is extremely fluffy and, thereby, sound absorbent: bats can only obtain a useful echo at short distances.

The bats also know how to make use of the Doppler effect. If a prey animal is moving towards the sound receiver of the bat, the frequency of the echo increases, and vice versa. This effect provides the bat with valuable information about the flight trajectory of its prey. The horseshoe bat intensifies its use of the Doppler effect: it also pays attention to the rippling of the frequency fluctuations on the sound wave of the echo that are caused by the wing beats of the prey. In this way, it won't mistake a leaf blown by the wind for a juicy moth. Some moths can again circumvent the biosonar, however. As soon as they notice the attacking bat, they fold up their wings and fall to the ground. A lifesaving strategy, because the bat's brain can only detect its prey when it is rhythmically flapping its wings.

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