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Sound Wars
How Bats and Bugs Evolve New Weapons and Defenses
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Bats and bugs are locked in a biological arms race of sorts. Insect-eating bats evolved new sonar technologies for tracking night-flying insects, which then developed better bat detectors and trickier defenses, driving the bats into stealthier attack plans, and so on. It's been going on for at least 50 million years. These sound-based interactions must be among the most complex predator-prey adaptations in nature.

Echolocation - emitting sounds, mostly above the range of human hearing, and analyzing the echoes that bounce back - allows aerial-feeding bats to detect, track, and assess potential prey. It lets them hunt flying insects under nighttime conditions that range from the confounding shadows of moonlight to the uniform darkness of an overcast night.
But there are two great disadvantages to echolocation. First, the dissipation of sound as it moves through air sharply limits the operational range of echolocation by bats. Most probably cannot detect a medium-sized insect beyond about 15 to 30 feet (roughly 5 to 10 meters). We know, for instance, that big brown bats (*Eptesicus fuscus*) first spot a three-quarter-inch (19-millimeter) sphere at 16.5 feet (5 meters).

One way to extend the range is to boost the strength of the signal. But that introduces the second disadvantage of echolocation: information leakage. The stronger the signal, the more likely it will be detected. Consider that the little brown bat (*Myotis lucifugus*) produces about 20 echolocation signals a second, each one registering 110 to 120 decibels when measured about four inches (10 centimeters) in front of the bat. (That's louder than the smoke detector in your home, which hits
about 108 decibels.) Echolocation signals make bats conspicuous and allow us to monitor them with electronic bat detectors that collect sounds beyond the range of human hearing.

Almost anywhere in the world, an observer with a tunable bat detector can eavesdrop on most aerial-feeding bats by selecting any frequency between 20 and 60 kilohertz. That bandwidth seems to give bats the best compromise between range and resolution. Yet, depending on where you were listening, you might notice that some bats produced no echolocation calls that could be heard by your detector. And with that fact, things get complicated.

In most places where our detectors find bats, other animals are also listening. Many insects, including species of moths, beetles, lacewings, mantids, and crickets, have their own bat detectors - ears tuned to the bats' signals. Biologists have determined, by monitoring activity of moths' auditory nerves, that most moths which have ears can hear best between 20 and 60 kHz.

The ability to detect the echolocation calls of a hunting bat gives the insect an edge - a chance to escape. When the moth detects a weak signal from a distant bat, it simply turns and flies away. The average moth can hear the average bat at about 130 feet (40 meters), almost 100 feet (30 meters) before the insect would even appear on the bat's screen. But when the signal is strong and the threat imminent, the moth's response is dramatic: It begins

flying erratically and may dive steeply toward the ground.

By experimentally deafening bat-detecting moths, scientists confirmed that moths with working ears have much less chance of being caught by bats than those whose ears are damaged. Red bats (*Lasiurus borealis*) and hoary bats (*Lasiurus cinereus*), for example, miss about 60 percent of their attacks on moths with bat-detecting ears.

So what is the poor bat to do? The answer lies partly in those bats whose calls go unheard by bat detectors. There are at least five strategies that help bats thwart the hearing-based defenses of their would-be prey.

Strategy 1: Lowballing
You can often hear the echolocation calls of western North America's spotted bats (*Euderma maculatum*) with your own ears, while your bat detector (tuned between 20 to 60 kHz) will miss them. Moths' ears have the same problem. The insects can't hear the low-frequency sonar signals (concentrated around 10 kHz) of spotted bats until the predator closes to within a few meters. Echolocation calls of some other aerial-feeding bats also use calls that are mostly below 20 kHz. These include many free-tailed bats, such as western bonneted bats (*Eumops perotis*) from the American Southwest, Midas free-tailed bats (*Mops midas*) from Africa, and white-striped free-tailed bats (*Tadarida australis*) from Australia. The penalty for using lower frequency sounds is that they have longer wavelengths, which provide less detail about targets and probably miss smaller objects altogether.

Strategy 2: Highballing
In tropical regions of Africa, India, Southeast Asia, and Australia, some bats use echolocation frequencies above 60 kHz. In fact, such species as Sundevall's roundleaf bat (*Hipposideros caffer*), Lander's horseshoe bat *(Rhinolophus landeri*), and dusky roundleaf bats *(Hipposideros ater*) have calls dominated by sounds above 100 kHz. Once again, the bat can sneak up on the insect because its calls are undetected until it's too late. As a general rule, however, higher frequencies mean a shorter effective range.

Strategy 3: Lower the volume
Many species of insect-eating bats use quiet echolocation calls of around 60 to 80 decibels, which insect detectors hear only when the bat gets within about three feet (one meter). Low-strength calls seem to be associated with gleaners - bats that snatch their prey from leaves, the ground, and other surfaces. These bats probably find their targets not with echolocation but by listening for sounds of the insect's movements or its efforts to attract a mate.

Strategy 4: Silence
Foraging California leaf-nosed bats (*Macrotus californicus*) and greater false vampire bats *(Megaderma lyra*) often stop producing echolocation calls entirely, apparently relying instead on vision and/or sounds made by moving prey. By saying nothing at all, these bats avoid the problem of information leakage. Both species are gleaners. Until recently, we had no evidence of aerial-feeding bats that turn off their echolocation system. In South Africa, however, big-eared free-tailed bats (*Otomops martiensseni*) do not always echolocate when hunting flying moths.

Strategy 5: Exploit insect behavior
Although their echolocation calls are very conspicuous to moths with bat-detecting ears, red bats, and hoary bats often feed largely on moths. At first glance, this seems anomalous.

But remember that not all moths have bat detectors, and analysis of moth remains in bat feces does not always let you determine whether the victim had ears. Yet we also know that red and hoary bats often catch moths that are fully equipped with bat-detecting ears. How do they do it?

The likely answer lies in the insect's defensive behavior. Once a moth hears a nearby bat and initiates its defensive flight, the behavior continues for several seconds. If the original bat,
or another close by, attacks while the moth is briefly on "autopilot," then the bat's odds of success increase dramatically - from 40 percent to more than 80 percent.

The diversity of bats and moths suggests we will discover many variations of this theme. Do bats sneak up on their insect prey? Several observations suggest that they sometimes do. Red bats hunting along tree lines seem to use the vegetation to screen their approach. And the rufous horseshoe bat (*Rhinolophus rouxi*), which sits on a perch waiting for potential prey to approach, may be using a similar tactic.

The story is far from complete and we have much to learn about these remarkable adaptations. For example, when threatened, some species of tiger moths (*Arctiidae*) produce clicks that affect the attack behavior of some bats. The clicks sometimes warn of the moths' bad taste, or they may startle the bat or otherwise interfere with its behavior. With hundreds of species of bats and many more species of tiger moths, further research will almost certainly reveal more complex interactions.

The shortcomings of echolocation, meanwhile, should be much less apparent when bats hunt prey other than insects. Like people, neither birds nor frogs can hear the echolocation calls of most bats. Information leakage should impose no penalty when fringe-lipped bats (*Trachops cirrhosus*), large slit-faced bats (*Nycteris grandis*) or greater false vampire bats hunt frogs, or when spectral bats *(Vampyrum spectrum*), large slit-faced bats, and giant noctule bats *(Nyctalus lasiopterus*) hunt birds. Mouse hunting is a bigger problem, though, since mice can hear higher-frequency sounds. And it turns out, at least in the laboratory, that greater false vampire bats do indeed shut up when hunting mice.

Bats that eat other bats should certainly do so in silence. But is that the case when Australian false vampire bats (*Macroderma gigas*), spectral bats, large slit-faced bats or big-eared woolly bats (*Chrotopterus auritus*) are on the prowl? We do not know. Nor do we understand what defenses bats might deploy against bat-eating bats.

As we learn more about bats and echolocation, we likely will find that we have but scratched the surface of sound-based interactions. Hints of what's to come include the 1999 discovery of flowers with acoustic nectar guides. These flowers reflect the Pallas' long-tongued bat's *(Glossophaga soricina*) echolocation calls to guide the foraging bats into just the right position for a drink and a dusting of pollen. Who knows where will it all end?

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