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Bats thrive in cluttered spaces

Kate Allen

The winged mammals produce high-frequency sounds and listen to their echoes from surrounding objects to track down insects to eat. Counterintuitively, the interference from the echoes of clutter nearby can help.

Remember Where's Waldo? Finding one character amid a visually cluttered page might be a fun game, but what if it was one you needed to play every night to survive? Like young readers searching for a man in a red-striped shirt in a sea of barber poles and candy canes, bats must identify small targets in large, busy environments. But unlike a casual Waldo seeker, bats must search while they actively avoid colliding with obstacles.

Just as visual clutter impairs the ability to find important information or objects, auditory clutter can interfere with the detection or identification of nearby sounds. Although reflective surfaces give sound life and richness and affect one's sense of space, people are rarely aware of their echoes or reverberation. Bats must distinguish the echoes from insects they are interested in from the echoes produced by trees, branches, buildings, and other bats in the colony. This quick study sheds some light on how bats navigate and hunt in the dark.

Hearing, interrupted

Bats echolocate targets in their environment by emitting repeated calls with brief pauses to listen for returning echoes. The delay from call to return determines the distance to a target, while intensity and spectral features determine its size and shape. But in cluttered environments, important sounds may become indistinguishable. When off-target clutter and target sounds reach a listener's ears within a short time period they interfere with each other, a phenomenon known as auditory masking. More intense sounds mask less intense sounds even when the sounds don't arrive at the same time. That effect is referred to as forward masking when the higher-intensity sound arrives slightly earlier and backward masking when it arrives slightly later.

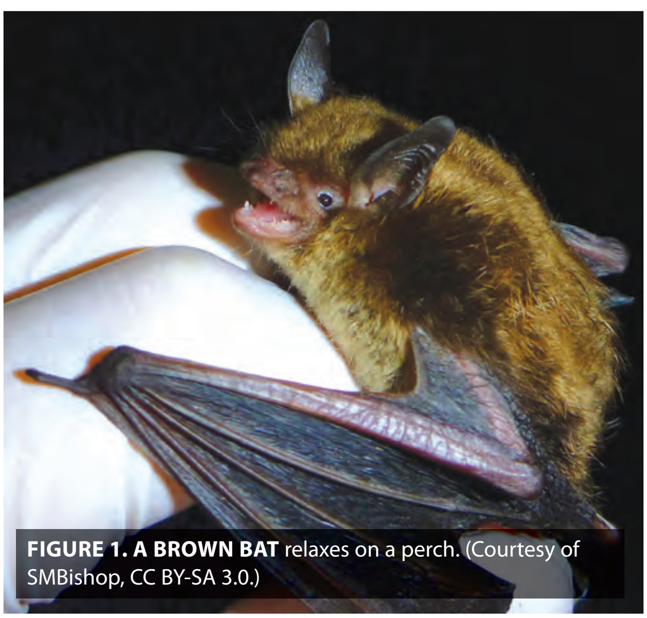

FIGURE 1. A BROWN BAT relaxes on a perch. (Courtesy of SMBishop, CC BY-SA 3.0.)

Objects that are too close to the animal may be masked by a loud outgoing call, whereas foreground objects may be masked by the echoes of background objects. What's more, clutter, such as the wall of a barn, is often large and reflective, whereas insects are small and absorbent. Large differences in returning sound pressure levels from obstacles and targets further exaggerate the masking problem.

Another challenge faced by bats is the interference between overlapping echoes from closely spaced objects. Big brown bats echolocate with sweeps of sound 1–10 milliseconds long. The echoes returning from distinct objects, such as an insect and the leaf it's sitting on, can overlap and produce an interference zone several centimeters wide.

The interfering echoes produce spectral peaks in which discrete frequency bands are out of phase with each other. Those overlapping frequencies from two or more echoes cancel each other out and create a single sound with distinct gaps in frequency. The result is a single, composite echo that may not resemble what the bat recognizes as "leaf" or "dinner." How bats translate the spectral profiles of composite echoes is central to understanding how bats perceive target shape.

Despite the challenges, the extraordinary animals remain highly successful in capturing prey in diverse environments and conditions. Bats have a few tricks to localize and track targets: They can shorten the duration of their call to minimize its overlaps with the echo, reduce call intensity to narrow their sonar angle and thus reduce echoes from clutter, and fly in trajectories that maximize the separation between targets and clutter. Such tricks indicate that bats are sensitive to the effects of reverberation and clutter, but not how those processes are encoded in the brain. The Batlab at Johns Hopkins is trying to understand the neural adaptations that allow brown bats, like the one shown in figure 1, to successfully find Waldo.

Signal in the noise

Contrary to interfering with auditory processing, clutter can potentially provide useful information. In a recent experiment,

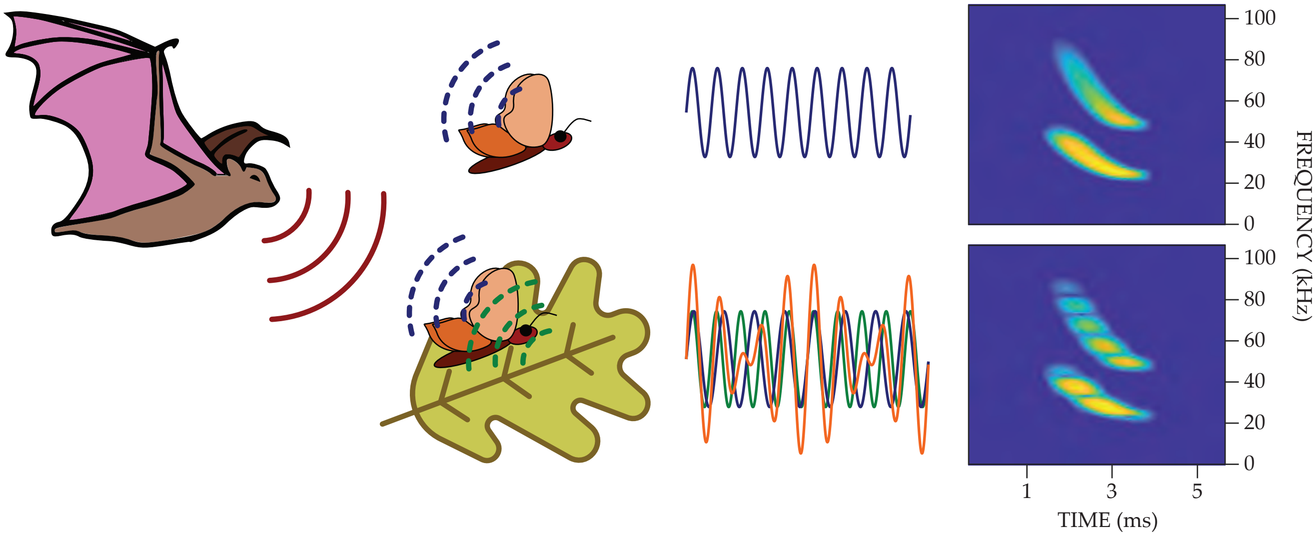

FIGURE 2. ECHOES IN CLUTTER are spectrally distinct from echoes in isolation. Bats use the frequency and temporal profiles of returning echoes (blue sine wave) to understand target size, shape, texture, and distance. In cluttered conditions, however, the two returning echoes (blue and green sines from moth and leaf, respectively) interfere with one another to produce a single composite echo (orange). That echo has distinctive notches in its spectrum that change the profile of the target echo. The notches may provide the bat with additional information about the target's size and its distance from the clutter.

the Batlab found that clutter can alter how targets are represented by the bat's brain. We created synthetic echolocation sounds by playing bat calls at objects and recording their echoes. We placed objects 10–20 cm in front of artificial houseplants—our in-lab simulacrum of natural clutter. The spacing simulated a clutter interference zone of varying overlap, and we also tested a no-clutter condition.

We then played those echoes to bats while recording the animals' neural responses in a brain region called the inferior colliculus. The area is a key part of the auditory pathway, where sound selectivity properties, such as frequency tuning, begin to emerge. We looked at responses of inferior-colliculus neurons and applied a classification algorithm to determine if they contained enough information to accurately discriminate which objects evoked a given neural response.

When we took a closer look at the responses to sounds recorded in and out of clutter, we found something unexpected: Sounds of objects with clutter 20 cm behind them are actually more easily discriminated by our classifier than sounds recorded in the no-clutter condition. That suggests that the bat brain gathers more information about targets near clutter, as shown in figure 2, than targets without any clutter. But objects placed too close to the clutter—within 10 cm—impair the brain's ability to distinguish object echoes. The discrimination of small objects benefits more from clutter than the discrimination of large objects. But those observations raised more questions than they answered and left us with more hypotheses to test.

One hypothesis for the effect is stochastic resonance. Adding low-level noise to a weak signal can increase the detectability of that signal by creating resonant frequencies that boost the signal above the detection threshold of a sensor. In that instance, the resonance provided by the slight, but not complete, overlap of clutter and target echoes may increase the amount of information available to the bat's brain about the target.

If that's the case, bats would benefit just as much from the addition of a white-noise broadcast from a speaker as they would from physical clutter present while they look for targets.

The counterhypothesis to stochastic resonance is that clutter may serve as an acoustic mirror. As the sound waves reflecting from clutter return to the bat, they interact with the target a second time. The interaction may allow those second echo returns to carry an additional spectral "silhouette" of the target. It gives the bat more information about the size and shape of the target in front of the reflective surface. My colleagues and I are currently running behavioral experiments to test these hypotheses. We wonder whether bats are as accurate in distinguishing between targets in clutter as the neural data suggest, and how well different surfaces reflect sound back to a bat's ears.

The benefits of clutter extend to human listeners as well. Reverberation longer than 50 milliseconds impairs how well speech sounds can be discriminated. Adding more sound-absorbing clutter to a space, such as an auditorium full of people, can reduce reverberation times and improve the ability to understand words in a talk. But if there's too little reverberation and the room becomes dry and unnatural sounding, listeners at the back may struggle to hear the speech at all. Indeed, sound waves in a dead room won't propagate well without artificial enhancement.

The role of acousticians is one of finding that right balance of clutter in perceptual spaces. All told, it seems that people shouldn't be in a rush to completely embrace minimalism when it comes to their ears.

I appreciate Clarice Diebold's help preparing figure 2.

Additional resources

► K. M. Allen et al., "Effect of background clutter on neural discrimination in the bat auditory midbrain," *J. Neurophysiol.* **126**, 1772 (2021).

► B. Møhl, A. Surlykke, "Detection of sonar signals in the presence of pulses of masking noise by the echolocating bat, Eptesicus fuscus," *J. Comp. Physiol. A* **165**, 119 (1989).

► C. F. Moss et al., "Active listening for spatial orientation in a complex auditory scene," *PLoS Biol.* **4**, e79 (2006).

► H.-U. Schnitzler, E. K. V. Kalko, "Echolocation by insect-eating bats," *BioScience* **51**, 557 (2001).

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