For horseshoe bats, wiggling ears and nose makes biosonar more informative

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Virginia Tech associate professor Rolf Mueller has discovered that small movements of horseshoe bats' ears and noses help them navigate in complex natural environments. This research has led to the design of a bat-inspired robotic sonar head, shown here being attached to a drone, with a movable 'noseleaf' and 'ears.' Credit: Logan Wallace/Virginia Tech

Humans, and most other mammals, have just four muscles joining their ears to their head. Bats have more than 20, and they use them to execute a precise series of wiggles, swivels, and twitches.

"In one-tenth of a second, three times as fast as you can blink your eyes, the bats can change the shape of their ears," said Rolf Mueller, an associate professor of mechanical engineering at Virginia Tech.

Mueller is the lead author of a new study, published in *Physical Review Letters*, demonstrating that these quick, precise movements underlie the bats' ability to wend their way through their world.

Bat echolocation is one of nature's remarkable achievements in navigation.

These nimble, nocturnal mammals emit ultrasonic pulses from their mouths or noses, depending on the species; the waves bounce off objects in the environment and are picked up again by the bats' ears. The reflected waves encode data about the bats' surroundings, helping them navigate and hunt in dark, crowded, hazardous environments.

Researchers don't yet completely understand how this biosonar system achieves its extraordinary accuracy. The bat gets just two incoming signals, one in each ear, and must construct a three-dimensional map detailed enough to allow them to zip through dense forests and routinely perform improbable sensory tasks—distinguishing a moth's wingbeat from the flutter of a leaf, for example.

One piece of the puzzle is the intricate structure of the bats' ears, which helps shape incoming pulses. For nose-emitting species like the horseshoe bats Mueller studies, similarly ornate structures called noseleaves act like megaphones to amplify and shape outgoing signals.

Now, Mueller has found that movements of the ears and noseleaves help, too, by packing extra information into every ultrasonic pulse the bats receive.

Over the last several years, his group has demonstrated that these rapid movements alter the ultrasound waves leaving the nose and the echoes entering the ears.

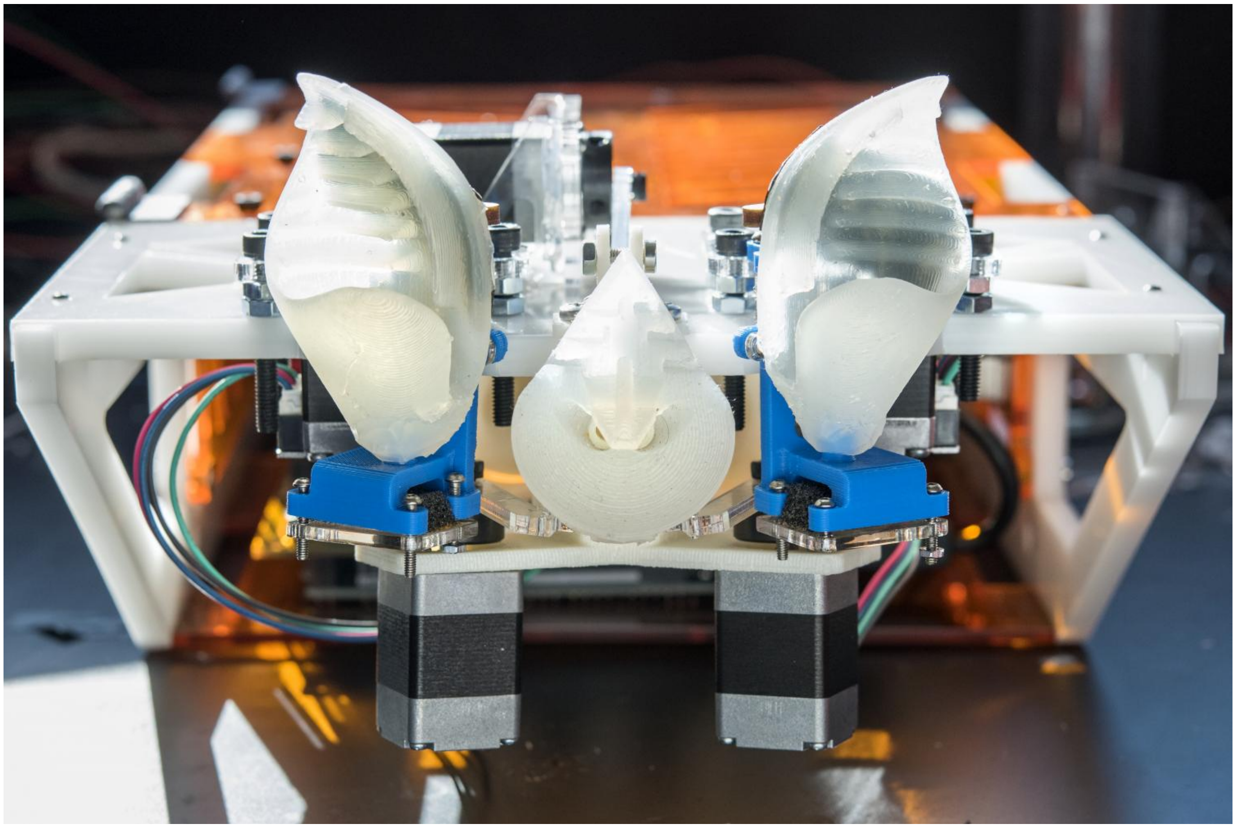
The new study is the first to demonstrate that these changes enrich the signals' information content. In particular, Mueller and his colleagues showed that the ability of the ears and noseleaves to adopt different conformations increases the bats' ability to localize the source of incoming signals.

To test whether the motion of horseshoe bat ears and noseleaves improves their biosonar performance, the team generated two models for each structure: a computational model and 3-D printed replica of the noseleaf and a computational model and simplified physical replica of the ear.

Each of the four models was tested in five different configurations, simulating the shape changes during biosonar emission and reception.

The researchers found that each of the five configurations provided a substantial amount of unique acoustic information. The farther apart two configurations were, the greater the difference in the signals, suggesting that these shape changes play a meaningful role in supplying more detailed data.

To investigate whether this additional information might be useful for echolocation, the researchers analyzed whether combining data from all five configurations improved a sensor's ability to localize the source of a sound wave.



This robotic sonar head mimics the emission and reception dynamics of the horseshoe bat, which uses small movements of the ears and noseleaf to encode extra information in sonar pulses. Credit: Logan Wallace/Virginia Tech

It did: combining five different configurations versus averaging five signals from the same configuration increased the maximum number of directions the sensor could distinguish by a factor of 100 to 1000, depending on the noise level.

The enhanced performance was consistent across all four models.

"What I found amazing was that the effect was very robust, even with the simplified models," Mueller said. "You don't need to reproduce all of the details of the real bat to see the effect of the motion."

That suggests that bolstering sensor capability by using a dynamic, mobile emitter and receiver should be translatable to engineered systems less complex than real bats, improving the navigation of autonomous drones and the accuracy of devices for speech recognition.

Directional resolution is likely just one function of the ears' and noseleaves' rapid motion, and the [bats](https://phys.org/tags/bats/) need more than just the direction of incoming signals to navigate through thickets and hunt in crowded swarms.

To investigate other aspects of biosonar performance, Mueller and his team are refining and updating their models and incorporating new bat species into their studies.

"There's always a next version," he said.

Provided by Virginia Tech

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