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Math answers puzzling behavior of bat ears, paving way for real-world upgrade to sonar tech

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Hiroshima University Assistant Professor Yasufumi Yamada posing with a photo of a greater horseshoe bat. Credit: Hiroshima University/Yasufumi Yamada

One iconic feature of the batsuit that makes Batman easily recognizable may soon give the Dark Knight's go-to sonar technology a real-world upgrade—bat-like ears. Only, these ears would not just look like a bat's, but would act like them, too.

Hiroshima University bioengineers wondering about the significance of bat ears' movements in echolocation created a mathematical model reflecting the behavior and learned the optimal pinnae motions that could amplify direction detection. Now, they plan to don sonars with moving pseudo-bat ears for a three-dimensional (3D) navigation system that is simple yet precise.

Their findings are published in the journal *PLOS Computational Biology* last October.

Unlike many mammals that rely on visual cues to make sense of their surroundings, bats, which are mostly nocturnal, mastered spatial mapping through auditory signals. They perceive the 3D environment by emitting ultrasound pulses from their mouth or nose and receive the returning echoes with their ears. Despite this simple active acoustic sensing design of one transmitter, their nose or mouth, and two receivers, their ears, these flight marvels can accomplish complex navigation tasks in the dark like pursuing prey or flying around without colliding with other bats in the group.

To locate their prey, bats need to know the distance and direction of their target. And evolution has equipped them with key anatomical features to accomplish these. But certain species have also come up with behavioral solutions to further refine their ability to detect the direction of an echo source. One of such behaviors observed in constant frequency–frequency modulated (CF-FM) bats is the movement of both ears as they echolocate. These species use a combination of CF and FM calls, the former are signals that retain their frequency throughout their duration while the latter's frequency changes over time.

Although the ear motions are believed to help the creatures in localizing the elevation angle of the sound source, their importance has yet to be fully understood.

Reverse engineering bat ears into lean, mean navigation machines

The three-person Japanese research team's model mirrors the active listening behavior of greater horseshoe bats belonging to the CF-FM group. They then used supervised machine learning to run exhaustive simulations to find out the role of ear movements in direction detection and which motions work best in accomplishing the task.

"For 3D spatial perception, certain species of bats have been well observed to move both ears with an antiphase pitch motion while listening to the echoes. However, the actual motions of both ears' movements look so complex. In order to theoretically solve the appropriate ear motions for 3D sound source direction detection, we conducted a mathematical simulation," said Yasufumi Yamada, the study's corresponding author and assistant professor at HU's Graduate School of Integrated Sciences for Life.

"To explain in more detail, the ear motion conditions required for direction detection are theoretically investigated through exhaustive simulations of the pseudo-motion of the ears, rather than simulations of the actual ear motions of bats. In this simulation, we assumed that the interaural sound pressure level difference of echoes contributes to the sound source direction detection."

Their investigation showed that only certain ear motions, namely three-axis rotation, allow for accurate and robust direction detection. It also provided strong support that the behavior observed in bats where they move their ears opposite each other helps them detect sound sources more accurately.

The researchers said their mathematical approach and findings could be used in designing new active sensing systems.

"Our theoretical investigations suggest that simply shaped hearing directionality and well-selected uncomplicated ear motions are sufficient to achieve precise and robust direction detection," Yamada said.

"In the future, we are going to demonstrate a practical sensing system equipped with two pseudo-moving ears. We hope to create a simple sonar system for 3D navigation systems inspired by bats."

More information: Takahiro Hiraga et al, Theoretical investigation of active listening behavior based on the echolocation of CF-FM bats, *PLOS Computational Biology* (2022). DOI: 10.1371/journal.pcbi.1009784

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