Bats shift Doppler effect

Professor *Gareth Jones* is head of the University's 'Batlab', housed in the School of Biological Sciences. His recent research has revealed the remarkable way in which bats avoid collisions and catch their prey.

Bats find their way at night and locate their food by emitting a series of quite loud ultrasounds that bounce off, and return an echo from, anything in their path. But in order to catch their prey they need to locate the target precisely in three dimensions and they do this by measuring the time delay between signal emission and echo reception.

Adaptations depend critically on the speed of the bat

However, flying bats will experience Doppler shifts (frequency shifts associated with motion) during echolocation. These Doppler shifts cause an increase in echo frequencies, which should result in errors of distance estimation and the bat missing its prey. But bats don't go hungry and Jones believes it is because they can minimise the errors caused by the Doppler effect, and hence improve their performance. Such modifications depend critically on the flight speed of the bat.

To test whether bats adjust their signals in this way, Jones and his postdoctoral assistant Marc Holderied used two methods for reconstructing bat flight paths. They developed stereo-video methods to locate flying bats in three dimensions, while simultaneously recording echolocation calls. They also used an array of microphones so that the bats' positions could be pin-pointed by measuring the different times of arrival of sound to each microphone. The results demonstrated a remarkable adaptation in echolocation.

What they found was that the faster a bat flies, the more it *overestimates* its distance from the target, because the frequency of the echo increases (pitch gets higher) due to Doppler shifts. But because the flying bat continues to approach the target between making the call and receiving the echo, the distance the bat flies reduces the distance that the sound travels, and accordingly the time delay of the echo is shortened. The bat therefore experiences a second error resulting in an *underestimate* of the target's distance, by half the distance flown. Because the first error creates an overestimation and the second an underestimation, bats can mutually cancel out both errors. To do this, however, they must actively adjust the design of their signals (and hence their susceptibility to Doppler effects) so that the resulting range overestimation is exactly compensated for by the range underestimation, due to the bat's own movement. By adjusting the frequency, duration and shape of their calls, bats can influence the distance at which these errors were cancelled out. Due to its similarity to focusing in optics, this distance is known as the 'distance of focus'.

Remarkably, Jones and Holderied's recordings of flying whiskered bats showed that the bats did indeed modify their call structure so that the distance of focus corresponded to the target of interest – a hedge in this case. However, distance measurement was most accurate at ranges slightly closer than the hedge's distance, which is interpreted as representing a security margin so the bats avoided collision with the hedge.

Reconstructions of flight paths from other species showed that faster-flying bat species emit calls with further distances of focus than slower-flying species. Thus bats can vary the structure of their echolocation calls to permit accurate measurement of distances related to the object of interest. Such sophisticated adaptations were found to occur within individuals, among individuals of a species, and among species. ■

The British Lesser Horseshoe bat

Gareth Jones

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