Echolocation in Bats

(order, Chiroptera)

Acoustic broadcast and detection for sample species

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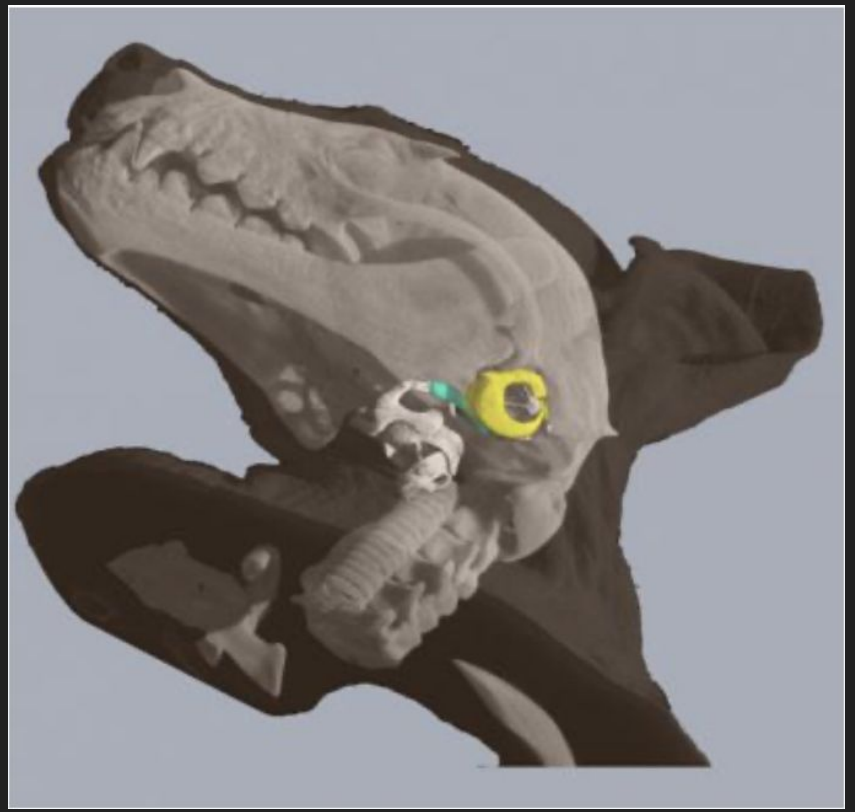
Echolocation

- Pulse emission, optimized for perception
- Echoes received and mentally processed to generate a visual understanding of the objects around them
- Echolocation yields object geometry, position, velocity, and even texture

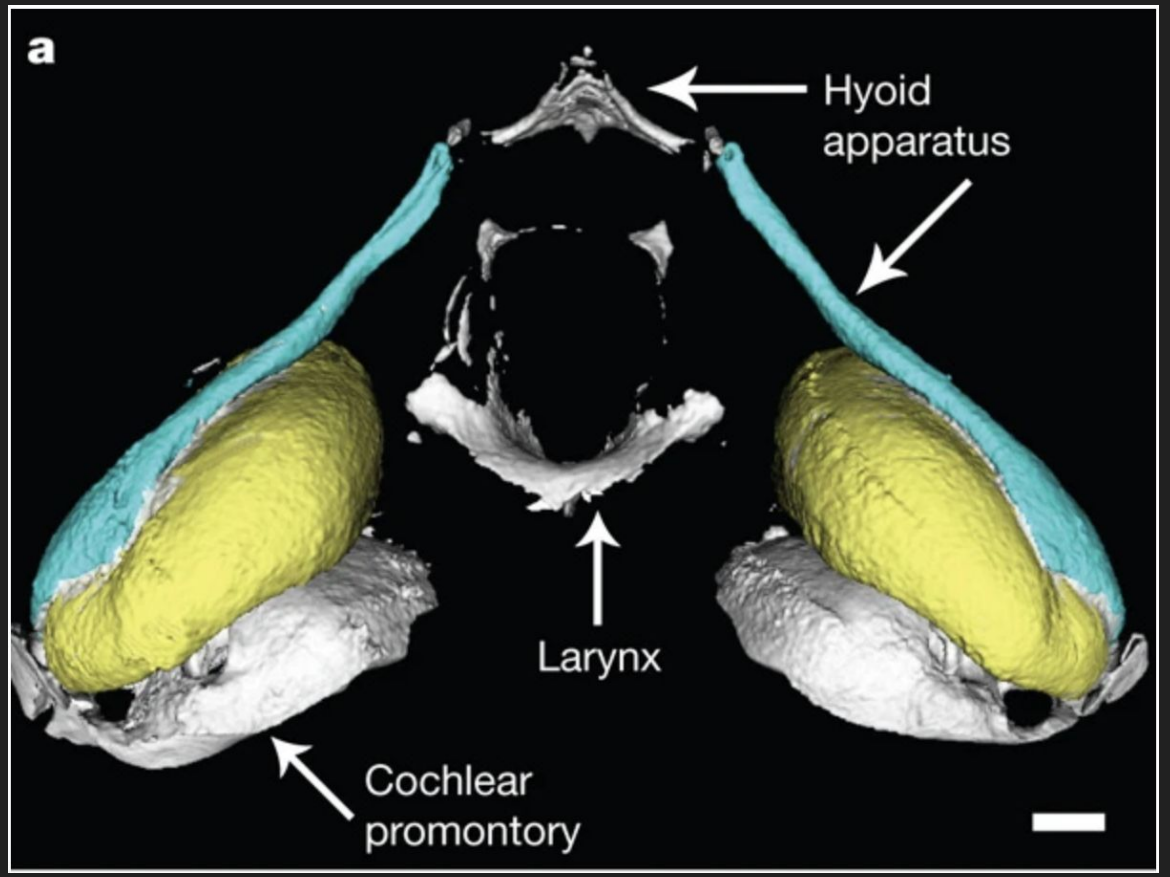
Production of Sounds

- Most bats echolocate using the larynx (a few use tongue clicks)



The Larynx

- The larynx:
  The stylohyal bone, which is attached to the tympanic bone, articulates to launch acoustic patterns



Phylogeny of Echolocation Sensors in Dominant Suborders

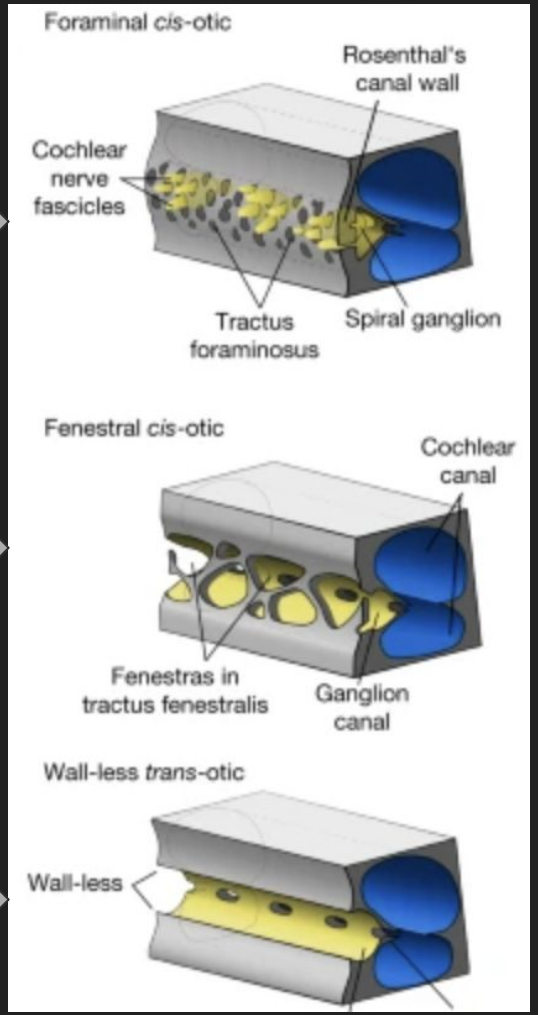
- Spiral ganglion: Structure of neurons in the cochlea that connect hair cells to the brain in mammalian inner ear.
- Rosenthal's canal wall: Houses the neurons of the spiral ganglion; comes in different architectures.

- Yangochiroptera (yang): suborder of bats with diverse echolocation capabilities.
- Yinpterochiroptera (yin): suborder of bats with inner ear structure similar to most non-bat mammals, with less echolocation diversity.

Rosenthal Wall Variants

Yin

Yang



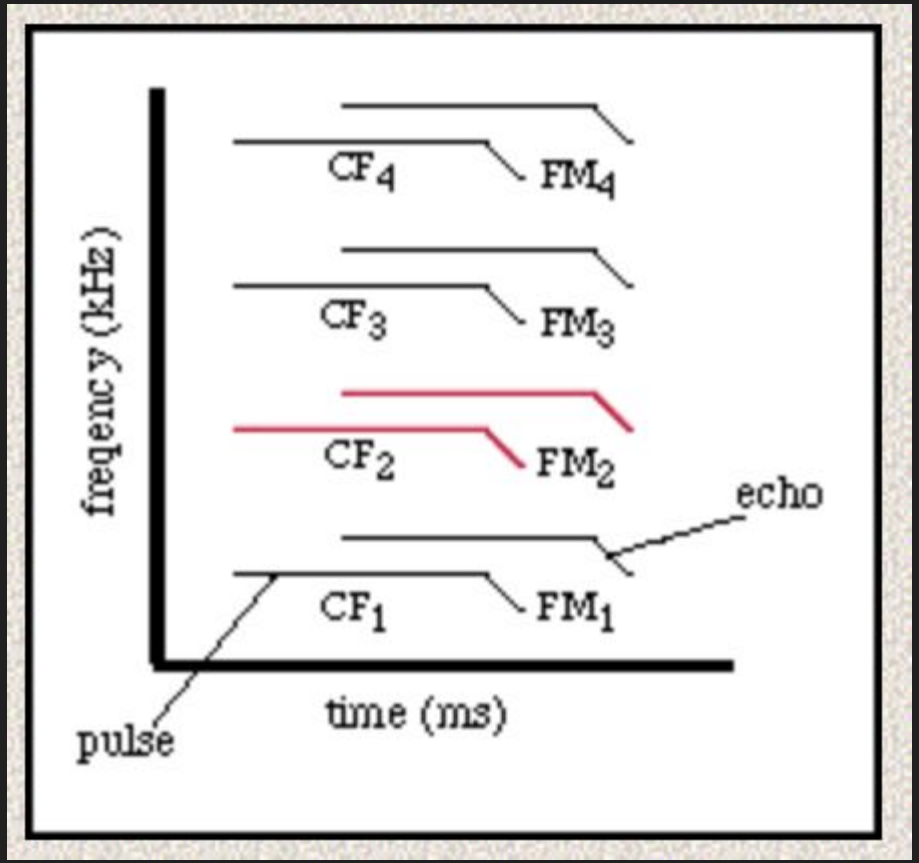
Call Characteristics

- Bats use constant frequency (CF) and frequency modulated (FM) broadcast pulses and sometimes both.
- The CF component is useful for initial detection of prey and analyzing prey features.
- The FM component aids in measuring distances from objects.

Bats make use of echo harmonics

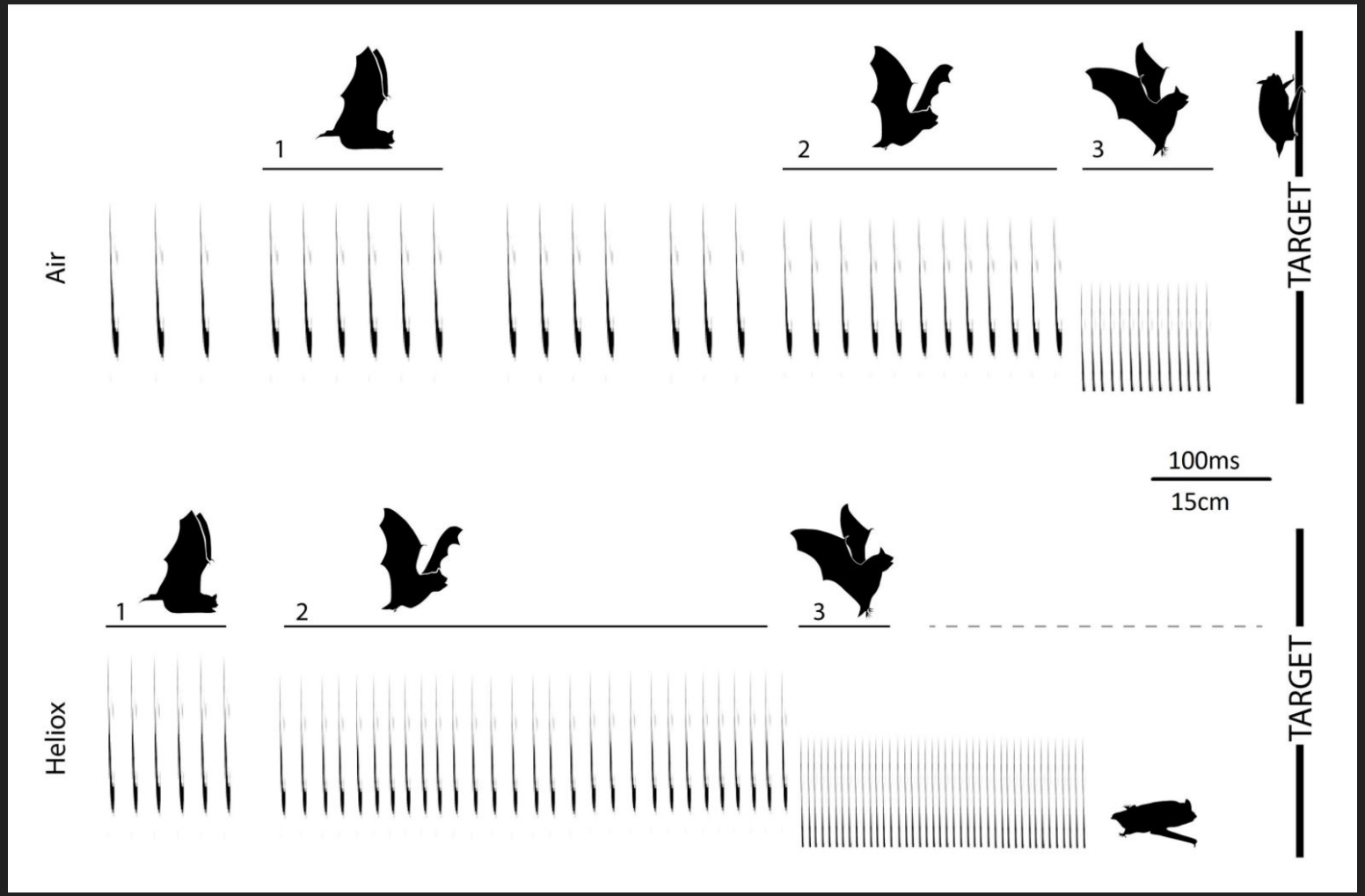
At right, lines at higher frequency (CF_2, CF_3 , etc.) represent higher harmonics of a given broadcast pulse and echo.

The moustached bat gains Doppler shift information from the echo second harmonic.



Innate Speed of Sound Reference

- Echolocation requires an understanding of the speed of sound.
- However, according to findings, an individual bat cannot adjust their innate sense of the speed of sound to adapt to the state of the ambient air around them.

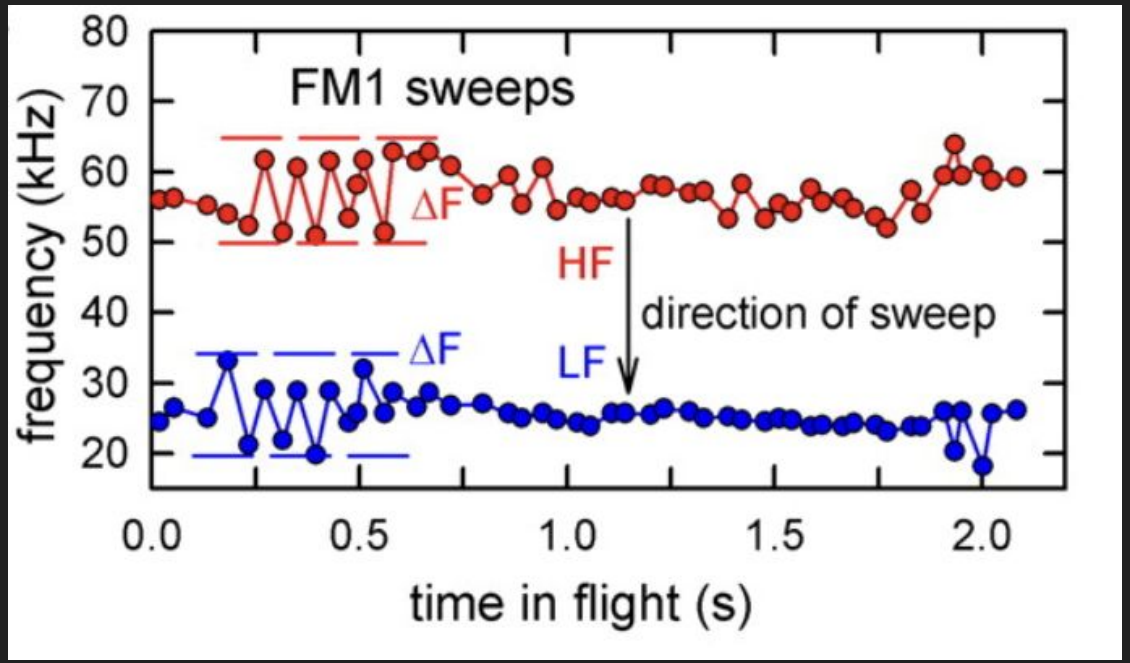

Air
1
2
3
TARGET
100ms
15cm
Heliox
1
2
3
TARGET

Predictive Echolocation

- Some bats generate a predictive model of their prey’s movement.
- They increase their broadcast pulse rate to correct an incorrect predictive model.

Object Cluster and Echo Ambiguity

- An issue is call-echo ambiguity for broadcast pulses emitted in quick succession.
- Correction involves changing the frequency range of the “downward FM sweep” that they commonly use in echolocation.



High frequency (red dot) and low frequency (blue dot) for an FM sweep in a single flight.
Each pair of dots (red and blue) represents a single broadcast pulse.

Successful Echolocation

- The echo frequency spectrum, intensity, temporal structure, and sonar aperture are important to echolocation.
- The sonar aperture is the range of incident angles that will result in a successful reflection of the incoming signal.
- The intensity of an echo is related to the reflectivity of the the object.

References

1. https://www.nature.com/articles/nature08737
2. https://www.pnas.org/doi/10.1073/pnas.2024352118
3. https://arxiv.org/pdf/2203.15770.pdf
4. https://www.pnas.org/doi/10.1073/pnas.2011719117
5. https://www.pnas.org/doi/full/10.1073/pnas.2005009117
6. https://www.pnas.org/doi/full/10.1073/pnas.1000429107
7. https://asa.scitation.org/doi/abs/10.1121/1.419024
8. https://www.nature.com/articles/s41586-021-04335-z
9. https://phys.org/news/2010-01-longer-echolocation.html