

# Adaptive sonar and flight behavior of the echolocating bat, *Eptesicus fuscus*

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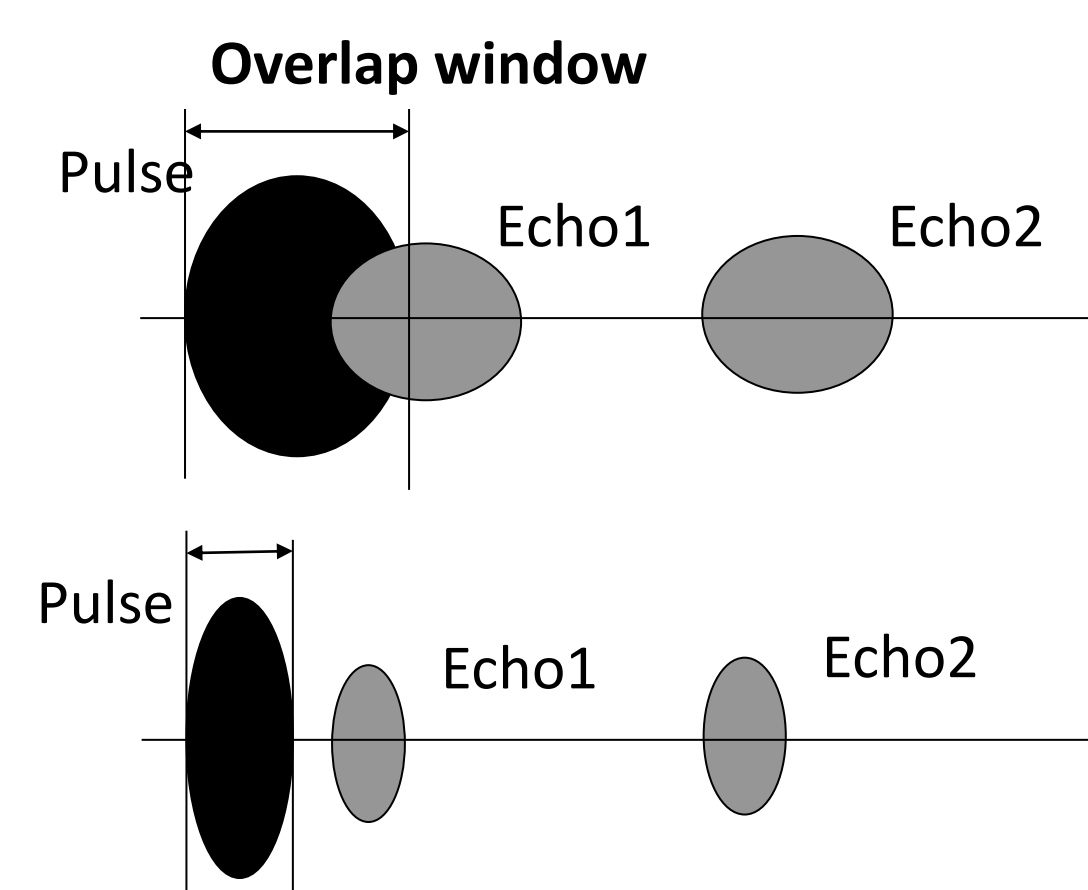
## Abstract

Echolocating bats emit ultrasonic pulses and listen for the returning echoes to gain information about their environment. Bats use echolocation for navigation, obstacle avoidance, and pursuit of prey. In this study, we examined how adaptive sonar and flight behaviors change with experience in a complex environment. We recorded the navigation behavior of the big brown bat, *Eptesicus fuscus*, in a laboratory flight room at the University of Maryland. The flight room was equipped with high-speed video cameras that permitted three-dimensional reconstruction of flight trajectories. Full-bandwidth acoustic recordings allowed characterization of the spectral and temporal content of sonar vocalizations. A microphone array along the walls of the flight room permitted reconstruction of the sonar beam axis, indicating acoustic gaze of the bat. Bats were trained to capture tethered mealworms located in the midst of an artificial forest, comprised of obstacles constructed to resemble trees. The position of the tethered mealworm was changed between trials. We found that the bat initially directed its sonar beam axis repeatedly towards each obstacle (tree) that it encountered as it flew through the forest, but after experience with the obstacles, the bat modified its behavior and shortened inspection time of the trees. The results of this study suggest the role of spatial attention and memory in navigation by echolocating bats.

## Background

Echolocating FM bats adapt the features of their vocalizations in response to information carried by sonar echoes:

- Duration adjustments – Bats avoid overlap between calls and echoes (Moss and Surlykke, 2010).
- Interval adjustments – Bats wait to receive echoes before producing next call (Wilson and Moss, 2004).
- Sound groups associated with target inspection – Bats inspect objects using sonar strobe groups (Moss et al., 2006).
- Direction aim – Bats sequentially point sonar beam at closely spaced objects (Surlykke et al., 2009).
- Frequency adjustments – Bats can associate echoes with vocalizations when call intervals are short enough to introduce ambiguity (Hiryu et al., 2010).



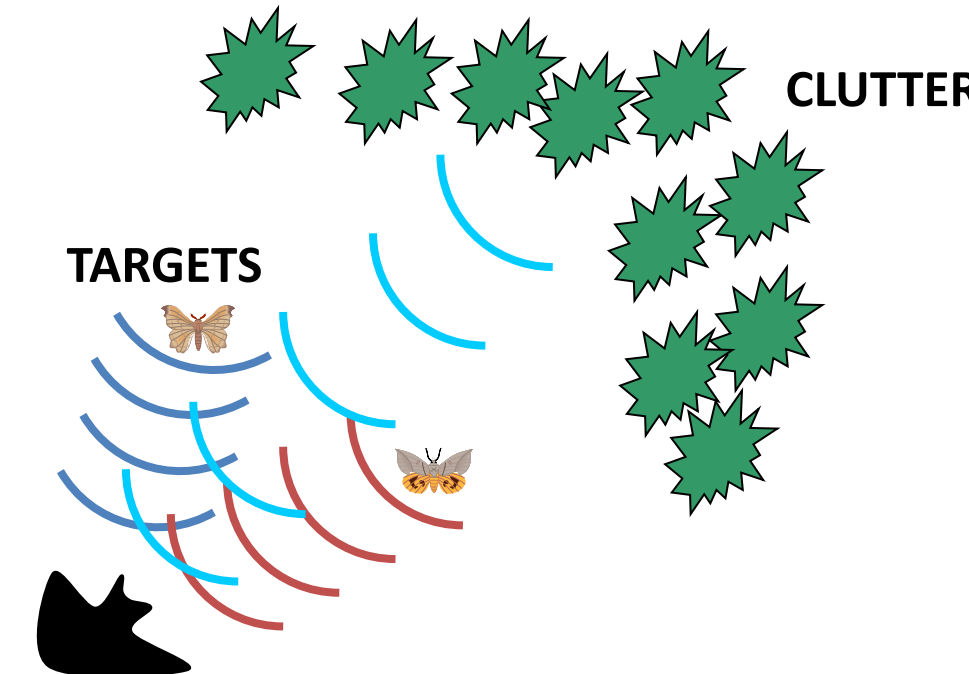
Adaptive sonar behavior provides indicators of:

- Information processed
- Information sought
- Attention to objects in the environment

Echolocating bats must organize acoustic information from multiple targets arriving from different directions and at different delays.

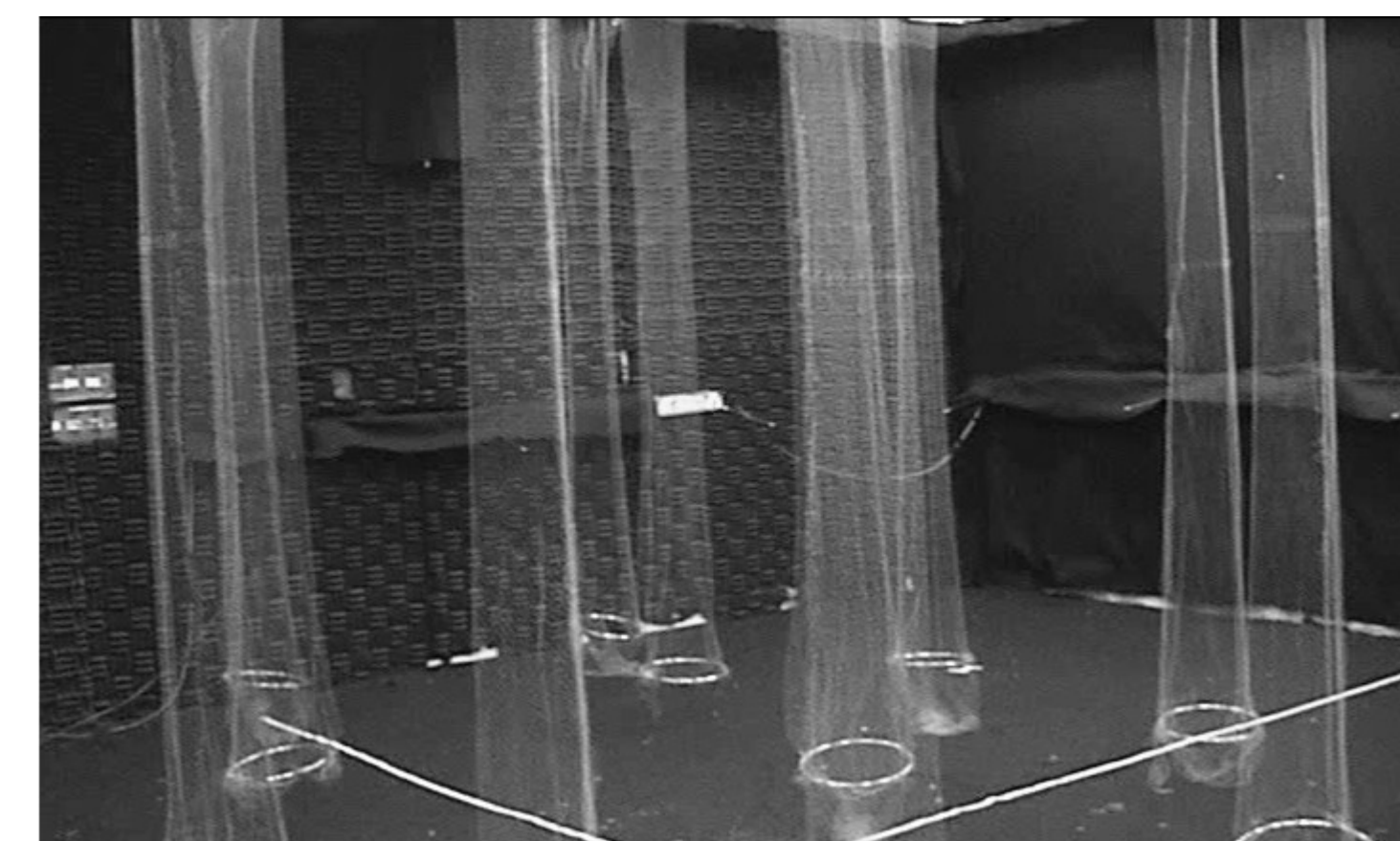
## How do bats negotiate a complex environment?

- Adaptive sonar behavior provides evidence for spatial attention to objects.
- Absence of adaptive sonar behavior suggests spatial memory guides navigation (Jensen, Moss, & Surlykke, 2005).



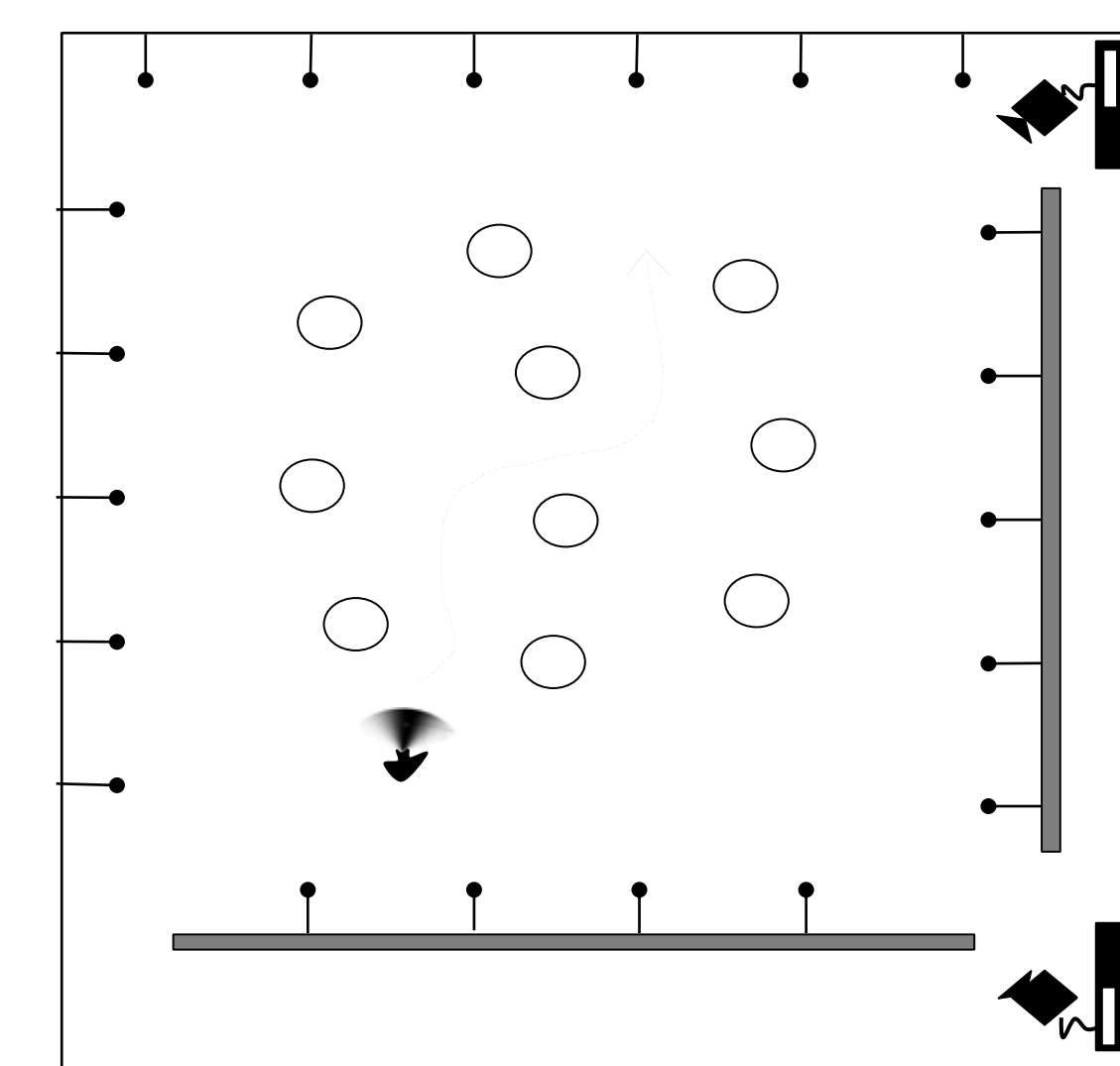
## Methods

Three bats were used in this study. Bats were flown in a laboratory flight room (7.3m x 6.4m x 2.5m) lined with acoustic sound-absorbing foam. The bat's sonar and navigation behavior was recorded during flight. Tethered mealworms were hung from the ceiling and placed in random locations in the room. Bats gained experience with the obstacles over a series of days.



Visually transparent "trees" permit continuous video tracking of bat

High speed infrared video permitted 3D reconstruction of the bat's flight path and a horizontal microphone array permitted reconstruction of the sonar beam along the horizontal plane. Floor microphones (not shown) recorded full-bandwidth sonar signals.

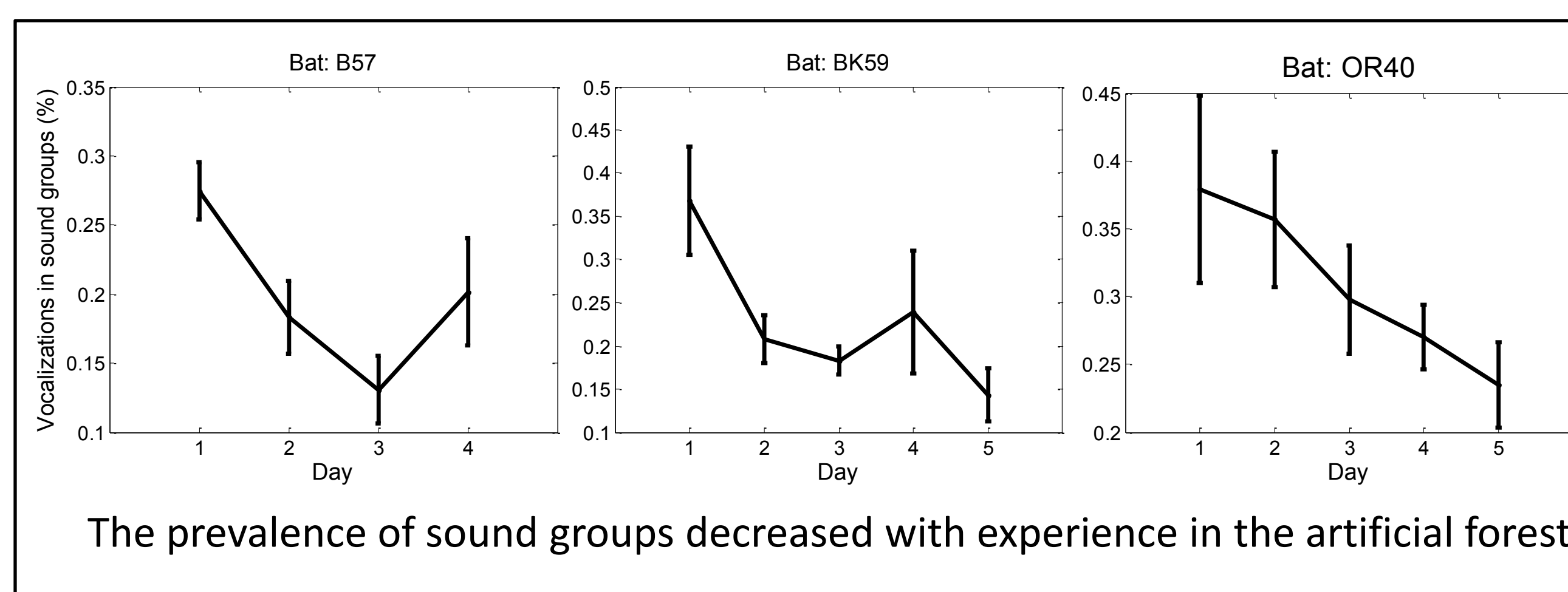
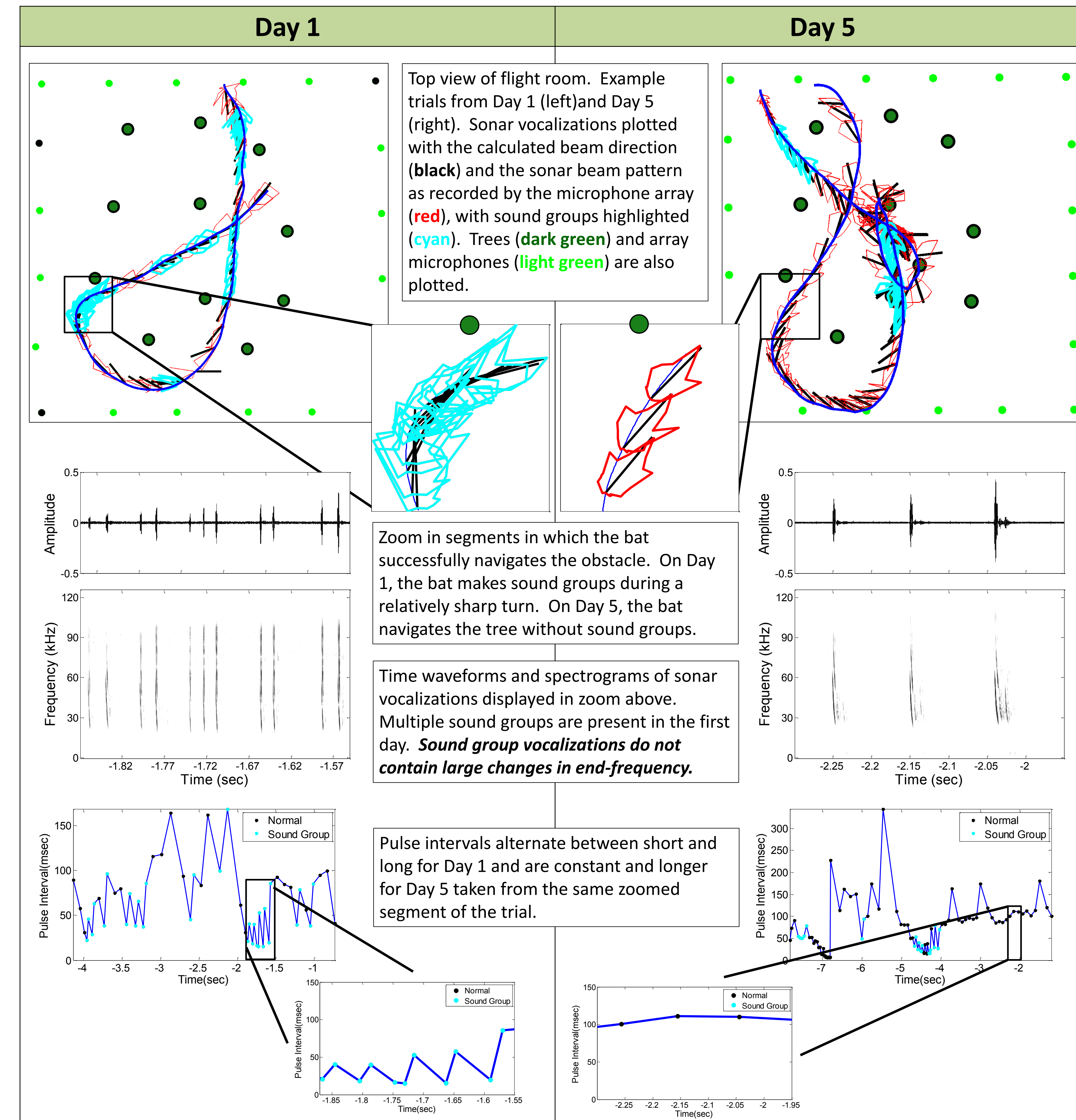


Top down view of the flight room with trees in the middle of the room and cameras and microphones along the walls

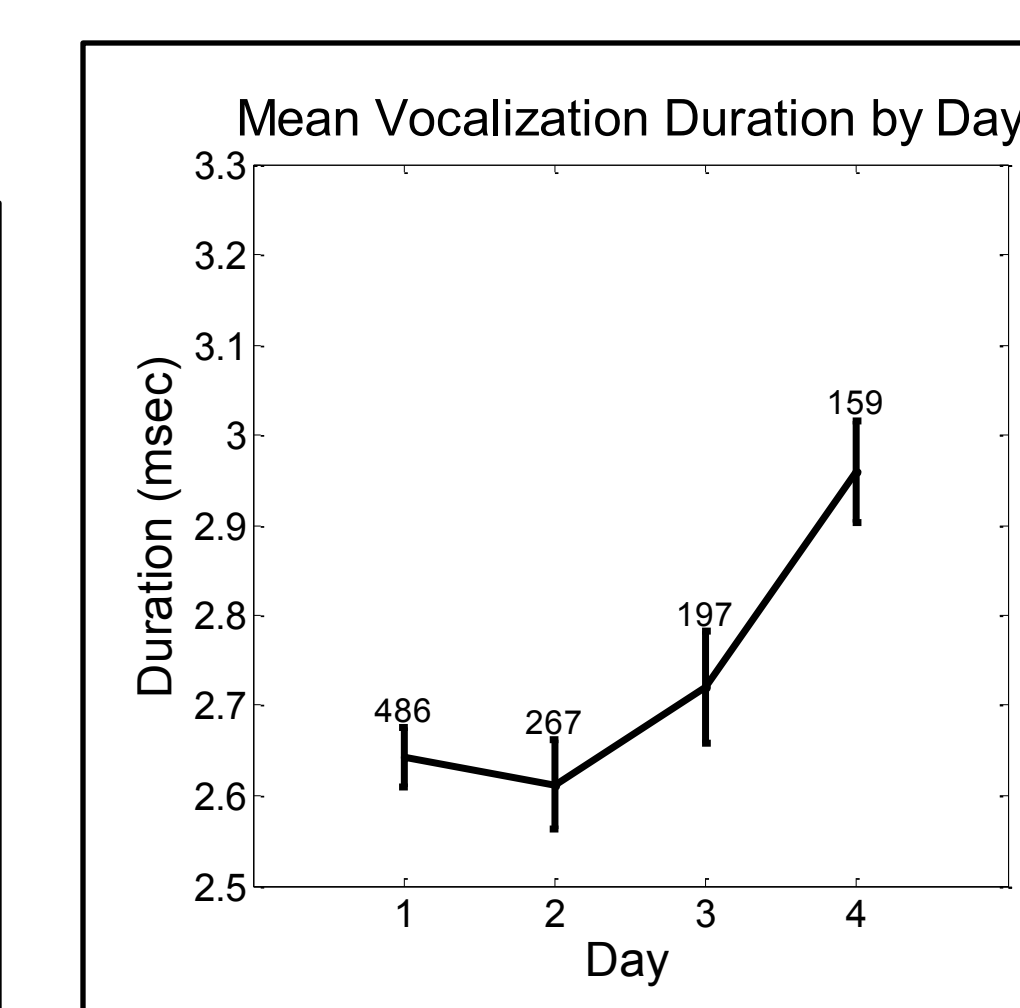
Sonar vocalizations were recorded and analyzed off-line. Measurements of the FM signal start and end frequency, duration, and intervals were taken for calls produced during behavioral trials. Sound groupings, when the bats emitted pairs or triplets of sounds with lower pulse intervals, were tracked. These sound groups were identified using a criterion that included stable pulse interval (5% tolerance), interrupted by longer breaks that exceeded 30% of the stable pulse interval.

## Results

### Directional Aim, Interval, Frequency and Duration of Sonar Calls



The prevalence of sound groups decreased with experience in the artificial forest



Vocalization duration increased with experience in the artificial forest

## Discussion

The adaptive vocal behavior of an echolocating bat provides a window to its perception of objects in its environment. The bat adjusts call duration to avoid overlap between vocalizations and echoes, it produces sound groups to sample information at a higher rate, and it aims its sonar beam at objects it inspects (Moss and Surlykke, 2010). It has also been reported that bats echolocating in a highly cluttered environment adjust the frequency of calls produced in strobe groups to facilitate the assignment of echoes at different delays with the appropriate sonar signal (Hiryu et al., 2010). The extent to which a bat adapts its vocal behavior in response to echoes can serve as a proxy for the animal's attention to objects in its surroundings.

Bats echolocating in a complex environment must sort echoes arriving from different directions and delays. This information processing load can be reduced if an animal learns its spatial environment. For example, an echolocating bat can reference the spatial information carried by a landmark to find its way through an obstacle course, and when the landmark intermittently provides an invalid cue, the bat fails to navigate correctly (Jensen et al., 2005).

In this task, the bat encountered artificial trees as it searched for tethered insect prey. The position of the trees was fixed from trial to trial, allowing the bat to build a spatial representation of the tree locations over time. The position of a tethered prey item, however, changed from trial to trial, so the bat could only find tethered prey by actively probing its environment through echolocation.

As the bat gained experience with the artificial forest, indicators of active attention to objects declined. Call duration increased across test days which could result in occasional overlap between sonar calls and tree echoes. The pulse-echo overlap suggests that the bat has shifted its attention to objects beyond the trees as it was searching for prey. The incidence of sonar sound groups also decreased over time. Adjustments in the spectral content of sonar calls within strobe groups was not observed in this study, perhaps because the echo returns from the trees were too weak to produce ambiguity in call-echo assignments. Changes in vocal behavior suggest that the bat relied more on spatial memory to negotiate the forest as it gained experience in the environment.

The results of this study point to the network of cognitive processes (spatial perception, attention and memory) that support spatial navigation and prey capture by bats operating in a complex environment.

## References

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