Echolocating bats emit high frequency sounds and listen to the returning echoes to detect, localize, and discriminate objects in their environment. Objects return altered versions of the original signal: amplitude, arrival time, and frequency spectra. Bats may use a combination of these cues for discrimination and identification of objects.

Previous studies have shown that bats can discriminate objects differing in fine structure (Griffin et al., 1965; Bridger, 1970; Simmons and Voisin, 1973; Simmons et al., 1974; Habersetzer and Volpe, 1983; Schmidt, 1988; Mogdans et al., 1993), but these studies did not investigate the role of adaptive echolocation behavior that may play an important role in perception by sonar.

Recent studies have shown that bats direct their vocalization beam on objects of interest during a difficult navigation task (Hurshlje, Ghose, & Moss, 2009). But how do bats behave in a difficult discrimination task and what role does adaptive echolocation behavior have in discrimination performance in free flying bats?

In this study we examine the bats' discrimination performance trained to discriminate a smooth object from different textured objects. We show that bats use sequential sonar scanning of stimuli to discriminate targets with different textures, controlling the directional aim of the beam axis to inspect closely spaced targets one at a time.

Methods

Four bats were used in this experiment, though only two were successfully trained in the task. Additionally, one fell ill 10 weeks after the experiment was begun, before testing was completed with all stimuli. Bats were maintained on mealworms (Tenebrio molitor) and vitamin water. We measured the discrimination ability of Eptesicus fuscus, trained to identify a smooth spherical bead (S+) from a variety of textured objects (S-). Bats were able to freely investigate the stimuli by flying around the objects. The objects were suspended 80 cm from the ceiling by monofilament fishing line.

The bat's 3-dimensional flight path was reconstructed using stereo images taken from high speed video recordings, sonar vocalizations were recorded in each trial and analyzed off-line. A microphone array permitted reconstruction of the sonar beam pattern, allowing us to study the bat's directional gaze and inspection of objects.

Using operant conditioning we trained bats to discriminate between the smooth object (S+) and the textured object (S-). Six different S- were used, as well as an additional smooth S+ for control trials. Object positions were randomly positioned in the room every trial. S+ and S- were present and suspended from the ceiling for the entire duration of each trial.

To begin each trial, the bat was released from a platform. When the bat correctly hit S+, a tone frequency sound was played from a loudspeaker and a food reward was provided on the platform where the bat would return. Before the next trial, during the placement of S+ and S-, the bat was restrained, unable to observe the movement of the objects. The bat was not restricted in its flight path.

In order to determine the acoustic characteristics of the echoes reflecting from the bead stimuli, ultrasonic recordings were taken. The bead stimuli were hung by a fishing line and suspended from the ceiling in a sound insulated acoustic chamber. Computer generated sounds were broadcast from an ultrasound loudspeaker at each of the beads, and the returning echoes were recorded. The sound generated was a frequency sweep from 110 kHz to 10 kHz with a duration of 1 mic. The average spectrum for each stimulus between 25 to 80 kHz was plotted, and the standard deviation from echo to echo across frequency was expressed as the thickness of the line.

Results

Summary Data

The previous 0.9 seconds prior to last vocalization during inspection of S- was segmented out for summary analysis. Duration, pulse interval, sweep rate, and distance were computed for the previous 0.9 seconds with each different S-type. Each of these metrics shows differences when the bat inspects different S-types.

Conclusions

Bats can discriminate textured objects using echolocation. The bats performance seems correlated with the variation in the variation in amplitude and spectra of the objects transfer function. The bat directs its sonar beam (and head aim) sequentially at each object during inspection. The bats sonar behavior resembles that of bats tracking and intercepting insect prey (Ghose et al., 2006). The bat shows differences in sonar and approach behavior during inspection of different S-. For S+ very similar to S-, duration decreases, pulse rate increases, pulse interval decreases, and distance at last vocalization is lower when compared to S- very different than S+.

Future Work

Design new stimuli with known roughness, scattering, and interference patterns and test bats with these and compare performance with echo recordings from these objects to gain a better understanding of the cues the bats use for texture discrimination.