

dynamic role for the vestibular system in orientation and flight control. Laboratory studies of flight behavior under illuminated and dark conditions in both static and rotating obstacle tests were carried out while administering heavy water (D2O) to bats to impair their vestibular inputs. *Eptesicus* carried out complex maneuvers through both fixed arrays of wires and a rotating obstacle array using both vision and echolocation, or when guided by echolocation alone. When treated with D2O in combination with lack of visual cues, bats showed considerable decrements in performance. These data indicate that big brown bats use both vision and echolocation to provide spatial registration for head position information generated by the vestibular system.

2:55

1pAB3. Bat's auditory system: Corticofugal feedback and plasticity. Nobuo Suga (Dept. of Biol., Washington Univ., One Brookings Dr., St. Louis, MO 63130)

The auditory system of the mustached bat consists of physiologically distinct subdivisions for processing different types of biosonar information. It was found that the corticofugal (descending) auditory system plays an important role in improving and adjusting auditory signal processing. Repetitive acoustic stimulation, cortical electrical stimulation or auditory fear conditioning evokes plastic changes of the central auditory system. The changes are based upon egocentric selection evoked by focused positive feedback associated with lateral inhibition. Focal electric stimulation of the auditory cortex evokes short-term changes in the auditory cortex and subcortical auditory nuclei. An increase in a cortical acetylcholine level during the electric stimulation changes the cortical changes from short-term to long-term. There are two types of plastic changes (reorganizations): centripetal best frequency shifts for expanded reorganization of a neural frequency map and centrifugal best frequency shifts for compressed reorganization of the map. Which changes occur depends on the balance between inhibition and facilitation. Expanded reorganization has been found in different sensory systems and different species of mammals, whereas compressed reorganization has been thus far found only in the auditory subsystems highly specialized for echolocation. The two types of reorganizations occur in both the frequency and time domains. [Work supported by NIDCO DC00175.]

3:15

1pAB4. Responses of inferior colliculus neurons are shaped by inhibitory projections from lower nuclei. George Pollak and Ruili Xie (Section of Neurobiology, Univ. of Texas, Austin, TX 78712, gpollak@mail.utexas.edu)

Bats are highly social animals that utilize a remarkably rich repertoire of signals for a variety of social interactions. This talk will explore how these signals are processed and represented in the inferior colliculus (IC) of Mexican free-tailed bats. Most IC neurons are selective for communication calls in that they respond only to some calls but not to others. The selectivity is due largely to inhibition. To evaluate the impact of the inhibitory projections from the dorsal or intermediate nucleus of the lateral lemniscus (DNLL and INLL), each nucleus was reversibly inactivated while responses of IC neurons to a suite of communication calls were recorded. Inactivation of both nuclei allowed these IC cells to respond to a larger number of calls, and thus become less selective than when the inhibitory innervation was intact. We therefore conclude that the inhibitory DNLL and INLL inputs to IC are functionally shaping the signal processing in the IC by suppressing some excitatory inputs. One consequence of the inhibition from these nuclei is that it shapes the selectivity of IC neurons for complex signals, allowing those IC cells to extract certain information from only some complex signals but not others. [Work supported by NIH Grant DC00268.]

3:35

1pAB5. Neural mechanisms underlying the analysis of sonar and social vocalizations: Spectral and temporal integration in the mustached bat. Jeffrey J. Wenstrup, Kiran Nataraj, Don Gans, and Kianoush Sheykholelami (Dept. of Neurobiology, Northeastern Ohio Universities College of Medicine, 4209 State Rte. 44, Rootstown, OH 44272, jjw@neoucom.edu)

The analysis of sonar echoes by the mustached bat depends on combination-sensitive neurons that respond best when distinct spectral elements of a sonar pulse and echo occur in a particular temporal relationship. Such integrative response properties underlie direct comparisons of acoustic features in outgoing pulses and returning echoes, comparisons thought to encode pulse-echo delay and other information-bearing features of echoes. These response properties are abundant in the auditory midbrain, thalamus, and cortex of the mustached bat. Combination-sensitive neurons utilize facilitatory and inhibitory neural interactions to create selective responses to acoustic features. The different interactions (facilitatory and inhibitory) originate in different stages within the ascending auditory pathway. Inhibitory interactions arise mostly in the auditory brainstem. Facilitatory interactions arise within the inferior colliculus, but also display the results of the inhibitory interactions originating at brainstem levels. These response properties are well suited to the analysis of sonar echoes, but similar combinatorial response properties are tuned to spectral elements outside sonar frequency bands, probably to elements of social vocalizations. It is therefore likely that the neural analysis of biosonar signals shares common features with the analysis of other vocal signals. [Work supported by the National Institute on Deafness and Other Communication Disorders.]

3:55-4:10 Break

4:10

1pAB6. Pinniped bioacoustics: Atmospheric and hydrospheric signal production, reception, and function. Ronald J. Schusterman, David Kastak, Colleen Reichmuth Kastak, Marla Holt (Long Marine Lab., Univ. of California, 100 Shaffer Rd., Santa Cruz, CA 95060, rjschust@ucsc.edu), and Brandon L. Southall (Office of Protected Resources, Silver Spring, MD 20910)

There is no convincing evidence that any of the 33 pinniped species evolved acoustic specializations for echolocation. However, all species produce and localize signals amphibiously in different communicative contexts. In the setting of sexual selection, aquatic mating male phocids and walruses tend to emit underwater calls, while male otariids and phocids that breed terrestrially emit airborne calls. Signature vocalizations are widespread among pinnipeds. There is evidence that males use signature threat calls, and it is possible that vocal recognition may be used by territorial males to form categories consisting of neighbors and strangers. In terms of

mother-offspring recognition, both otariid females and their pups use acoustical cues for mutual recognition. In contrast, reunions between phocid females and their dependent pups depend mostly on pup vocalizations. In terms of signal reception, audiometric studies show that otariids are highly sensitive to aerial sounds but slightly less sensitive to underwater sounds. Conversely, except for deep-diving elephant seals, phocids are quite sensitive to acoustic signals both in air and under water. Finally, despite differences in absolute hearing sensitivity, pinnipeds have similar masked hearing capabilities in both media, supporting the notion that cochlear mechanics determine the effects of noise on hearing.

4:30

1pAB7. Cognitive processes in bird song. Jeffrey Cynx (Dept. of Psych., Vassar College, Poughkeepsie, NY 12604, chaos@vassar.edu)

Anthropomorphic hypotheses can alter previous ethological concepts. Songbirds have been traditionally categorized as open- or close-ended learners. Open-ended learners such as canaries and starlings continue to learn new songs throughout life. Close-ended learners such as song sparrows and zebra finches appear to learn song once and then repeat this song in a stereotyped or crystallized manner for the rest of their lives. Research over the last dozen years or so has produced evidence that whatever is close-ended in songbirds may be more than a little ajar. It is clear that adult song is a highly dynamic and closely monitored act. In these regards, it has a number of cognitive processes similar to human speech. Birds appear to continually monitor their own song, being able to stop in midsong if necessary. They also regulate the song amplitude given environmental and social conditions, and show song perturbations when experiencing delayed auditory feedback. However, so far as is known, close-ended learners cannot learn new song elements from a model, although there are hints to the contrary, including both behavioral and physiological results.

Contributed Papers

4:50

1pAB8. Human listening studies reveal insights into object features extracted by echolocating dolphins. Caroline M. DeLong (New College of Florida, 5700 N. Tamiami Trail, Sarasota, FL 34243, cdelong@ncf.edu), Whitlow W. L. Au (Hawaii Inst. of Marine Biol., Kailua, HI 96734), and Herbert L. Roitblat (DolphinSearch Inc., Ventura, CA 93001)

Echolocating dolphins extract object feature information from the acoustic parameters of object echoes. However, little is known about which object features are salient to dolphins or how they extract those features. To gain insight into how dolphins might be extracting feature information, human listeners were presented with echoes from objects used in a dolphin echoic-visual cross-modal matching task. Human participants performed a task similar to the one the dolphin had performed; however, echoic samples consisting of 23-echo trains were presented via headphones. The participants listened to the echoic sample and then visually selected the correct object from among three alternatives. The participants performed as well as or better than the dolphin ($M = 88.0\%$ correct), and reported using a combination of acoustic cues to extract object features (e.g., loudness, pitch, timbre). Participants frequently reported using the pattern of aural changes in the echoes across the echo train to identify the shape and structure of the objects (e.g., peaks in loudness or pitch). It is likely that dolphins also attend to the pattern of changes across echoes as objects are echolocated from different angles.

5:05

1pAB9. Biosonar performance of foraging Blainvilles beaked whales (*Mesoplodon densirostris*). Peter T. Madsen, Mark Johnson, Peter L. Tyack (Woods Hole Oceanogr. Inst., Woods Hole, MA 02543), Natacha Aguilar de Soto (La Laguna Univ., Tenerife, Canary Islands, Spain), and Walter M. X. Zimmer (NATO Undersea Res. Ctr., 19138 La Spezia, Italy)

Echolocating animals like bats and toothed whales navigate and locate food by means of echoes from sounds transmitted by the animals themselves. Toothed whale echolocation has been studied intensively in captivity, but little information exists on how echolocation is used by wild animals for orientation and prey location. To expand on this issue, a noninvasive, acoustic Dtag (96-kHz sampling, 16-bit resolution) was deployed on two Blainvilles beaked whales. The tagged whales only clicked at depths below 200 m during deep foraging dives. The echolocation clicks are directional, 250-ms transients with peak energy in the 30–40-kHz band. Echoes from the seafloor and from prey items were recorded. The regular click rate is not adjusted to the decreasing echo delay from incoming prey until the target is within an approximate body length of the whale after which the click rate is increased rapidly akin to the buzz phase of echolocating bats. This suggests that the whales use different sonar

strategies for operating in near versus far field modes. Changes in received echo intensities from prey targets during approaches are compared to the active gain control in the receiving system of bats and in the transmitting system of dolphins.

5:20

1pAB10. Aerial hearing sensitivity in some pinnipeds is comparable to that of humans. Colleen Reichmuth Kastak, David Kastak, Marla M. Holt, Ronald J. Schusterman (Univ. of California, Long Marine Lab., 100 Shaffer Rd., Santa Cruz, CA 95060, coll@ucsc.edu), and Brandon L. Southall (NOAA Fisheries Acoust. Prog., Silver Spring, MD 20910)

Aerial hearing sensitivity was measured in pinnipeds in a sound attenuating, hemi-anechoic chamber. Thresholds at 12 frequencies between 0.1 and 32.5 kHz were obtained behaviorally for three individuals (a California sea lion, a harbor seal, and a northern elephant seal) and compared to thresholds obtained using headphones in less controlled testing environments. The thresholds measured in the chamber revealed the expected relative changes in sensitivity with frequency; however, the absolute sensitivities were much better than had been previously measured. Harbor seal thresholds were on average 25 dB lower with best sensitivity of -2 dB ($re: 20 \mu\text{Pa}$) at 3.2 kHz. Elephant seal thresholds averaged 23 dB lower with best sensitivity of 27 dB ($re: 20 \mu\text{Pa}$) at 0.4 kHz. Thresholds for the California sea lion were also much lower than expected, with best sensitivity of 1 dB ($re: 20 \mu\text{Pa}$) at 12 kHz. The thresholds measured for the sea lion and harbor seal rival those of human subjects at some frequencies, and suggest that previously reported aerial hearing thresholds in pinnipeds were significantly noise limited. Further, the results indicate that these pinnipeds have greater sensitivity in air than in water when comparisons are made in terms of sound pressure.

5:35

1pAB11. A computational model of echolocation: Transformation of spectrogram into the reflected intensity distribution for range discrimination of multiple closely spaced objects. Ikuro Matsuo, Kenji Kunugiyama, and Masafumi Yano (Res. Inst. of Elec. Commun., Tohoku Univ., 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan, matsuo@riec.tohoku.ac.jp)

Using frequency-modulated echolocation, bats can discriminate the range of objects with an accuracy of less than a millimeter. However, the echolocation mechanism is not well understood. The delay separation of three or more closely spaced objects can be determined through analysis of the echo spectrum. However, delay times cannot be properly correlated with objects using only the echo spectrum because the sequence of delay