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Echolocation in Dolphins

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1. Introduction

Echolocation is the process by which an organism projects acoustic signals in order to obtain a sense of its surroundings from the echoes it receives. In a general sense, any animal with a capability to hear can echolocate by emitting sounds and listening to the echoes. A person in an empty room can gain an idea of the size and shape of the room by emitting sounds and listening to the echoes from the different walls. However, in this chapter echolocation is used in a more specific sense in which an animal has a very specialized capability to determine the presence of objects considerably smaller than itself, discriminate between various objects, recognize specific objects, and localize objects in three-dimensional space (determining range and azimuth). Dolphins and bats have this specialized capability of echolocation.

A dolphin’s ability to survive and thrive in an aquatic environment is maximized by its ability to echolocate. Acoustic energy propagates in water more efficiently than almost any other form of energy, making the use of acoustics ideal for the aquatic environment. Many species of dolphins can be found in shallow offshore waters, bays, and rivers where the water can be extremely turbid with very limited underwater visibility. Under these conditions, the ability to echolocate becomes critical for navigating, locating and catching prey, and avoiding predators.

The echolocation system of a dolphin can be broken down into three subsystems, the transmission, reception, and signal processing/decision making subsystems. The transmission system consists of the sound producing mechanism, acoustic propagation from within the head of the dolphin out into the water, and the characteristics of the signals traveling in the surrounding environment. The sound production mechanism is discussed by Cranford in Chapter 3 and the propagation of the signals through the dolphin’s head is addressed by Aroyan et al. in Chapter 10. The receiving subsystem consists of the auditory system of the animal, and its capabilities depend on the characteristics of the peripheral and higher auditory centers.
of the auditory central nervous system. The characteristics of the dolphin auditory system is discussed by Nachtigall et al. in Chapter 8 and the auditory central nervous system is discussed by Ridgway in Chapter 6.

The capability of a dolphin to detect objects in noise and clutter and to discriminate between various objects depends to a large extent on the information-carrying capabilities of the emitted signals. Also important are the extent to which the dolphin’s auditory system can extract pertinent information from the echoes and the animal’s cognitive capabilities. In order to make optimal use of acoustical information, the dolphin should have an auditory system that is very sensitive over a wide frequency range. The dolphin should also be sensitive in both quiet and noisy environments and should be able to detect short- and long-duration sounds. A good spectral analysis capability is important in discriminating and recognizing predators, prey, and other objects in the environment. Other important characteristics of a good sonar receiver include the ability to spatially resolve and localize sounds, reject externally generated interferences, and recognize temporal and spectral patterns of sounds.

2. The Transmission System

Dolphins produce sounds within their nasal system, and the signals are projected out through the melon (Cranford, Chapter 3; Aroyan et al., Chapter 10). Although there has been a long-standing controversy over whether sounds are produced in the larynx or in the nasal system of odontocetes, almost all experimental data with dolphins indicate that sounds are produced in the nasal system (Au 1993). The melon in front of the nasal plug may play a role in channeling sounds into the water, a notion first introduced by Wood (1964). Norris and Harvey (1974) found a low-velocity core extending from just below the anterior surface toward the right nasal plug, and a graded outer shell of high-velocity tissue. Such a velocity gradient could channel signals originating in the nasal region in both the vertical and horizontal planes. Using both a two-dimensional (Aroyan et al. 1992) and a three-dimensional model (Aroyan, 1996; Aroyan et al., Chapter 10) to study sound propagation in a dolphin’s head, Aroyan has shown that echolocation signals most likely are generated in the nasal system and are channeled into the water by the melon. Cranford (Chapter 3) has also collected evidence that suggests that echolocation signals are most likely produced in the nasal system at the location of the monkey lips-dorsal bursae complex just beneath of the blow hole.

Echolocation signals seem to fall into two general categories. The first category is associated with signals produced by dolphins that can also produce whistles. Whistles are frequency-modulated signals of relatively long duration (1 to 3 s) and are described by Tyack and Clark in Chapter 4. The properties of signals produced by dolphins that can also whistle will be