The cognitive dolphin
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Although we may not be able to say definitively what it is like to be a dolphin, there is a good deal that we can know about its perceptual and cognitive system. My work, along with my colleagues and students, has been dedicated to discovering what kinds of representations animals have and how those representations underlie its behavior. The highlight of this research is our work on dolphin biosonar echolocation. Most of this work involves the Atlantic bottlenose dolphin (*Tursiops truncatus*), though we have on occasion studied other species as well. Like bats, dolphins obtain information about the identity, location, and characteristics of objects in their world by actively interrogating them using their unique biological sonar, which is highly adapted to their aquatic environment. Although their use of biological sonar is called echolocation, it is used for far more than just determining how far away objects are. Using echolocation, dolphins can identify many characteristics of submerged objects, including size, structure, shape, and material composition. For example, dolphins can detect the presence of small (7.6 cm, diameter) stainless-steel spheres at distances up to 113 m. They can discriminate between aluminum, copper, and brass circular targets, and they can discriminate between circles, squares, and triangular targets covered with neoprene (see Au 1993).

Bottlenose dolphin biological sonar uses very broad-band high frequency clicks, which emerge from the rounded forehead or melon as a highly directional sound beam with 3 dB (half power) beamwidths of about 10˚ in both the vertical and horizontal planes (Au et al. 1986). Their echolocation clicks have peak energy at frequencies ranging from 40 to 130 kHz with source levels of 220 dB re: 1 µPa at 1 m, (Au 1993). The time between successive clicks depends on the distance between the animal and the target it is scanning. The average time between emitted clicks in a train is typically 15 - 22 msec longer than the time required for the click to travel through the water to the target and return as an echo (Morozov et al. 1972; Penner 1989).

Dolphins can detect and discriminate targets in highly cluttered and noisy environments (Au 1993). Their biosonar abilities far exceed those of any man-made system. One outstanding example of the dolphin's keen sonar capabilities is their ability to sonically detect, dig out, and feed on fish and small eels buried up to 45 cm beneath the sandy seabed (Rossbach and Herzing 1997).

Dolphin hearing extends to frequencies as high as 150 kHz, 8-10 times as high as human hearing limits. They echolocate by sending brief (about 50 µsec) clicks. These signals are generated deep within their heads by passing air through a nasal structure called "monkey lips" because of their appearance. The sound travels through the water in a narrow cone-like beam and reflects off objects in that beam. The sound is picked up in the dolphin's jaw and conducted to the animal's inner ear, where it is transduced into neural signals for processing by the rest of the brain.

Although both bats and dolphins use echolocation, the characteristics of the medium in which their signals are emitted, the mechanisms by which the signals are produced, the type of signals, and the neurological apparatus they use to processes those signals differ substantially. Bat biosonar is adapted for use in air, whereas dolphin biosonar is adapted for use underwater. Bat biosonar signals are relatively long in duration (up to several msec), and contain both narrow-band constant-frequency and frequency-modulated components depending on the species (Bellwood 1988; Fenton 1988; Suthers 1988). By contrast the dolphin echolocation signal is very broadband and extremely short (about 50 µsec). Echoes typically range in duration from 50 to 200 µsec.

Dolphin echolocation is one of the most sophisticated cognitive processes that have been studied. When a dolphin uses its biological sonar to recognize objects its brain performs the equivalent of some extraordinarily complex computations. These computations transform one-dimensional sound waves arriving at each of the dolphin's two ears into representations of