SSC Pacific Scientists Study Marine Mammals to Build a Better Sonar

New Research Focuses on How Sounds are Processed

ALTHOUGH SYNTHETIC UNDERWATER sensors have improved in target detection over the last two decades, dolphins still outperform them when it comes to mine detection and classification. A project led by bioacoustic research scientist Dr. James Finneran at the Space and Naval Warfare Systems Center (SSC) Pacific is attempting to rectify this by improving our understanding of dolphin auditory physiology.

Dolphins utilize echolocation, a high-frequency, natural sonar system, to detect and classify targets in "noisy" environments. In the ocean, this translates to near-shore environments, where there is a high level of ambient noise from ships and from wave action against piers and the shore. Put simply, the animal emits a series of sound pulses and compares each to its corresponding returning echo to determine location and identity of an object.

Attempts have been made to improve manmade sonar systems by emulating the dolphin's transmit and receive signals, but these efforts have produced limited success with target recognition. Instead of simply mimicking the dolphin's own signals, this project team is attempting to replicate the manner in which a dolphin forms mental representations of a target.

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Dolphins & the Navy

The U.S. Navy has been training dolphins to perform various tasks since the early 1960s. Researchers found that dolphins and sea lions are highly reliable, easily trainable animals that excelled at delivering objects to divers, performing underwater surveillance, and locating underwater targets such as mines. Though it may sound like dangerous work, mines are made so that they cannot be set off easily by wave action or marine animals touching or bumping into them. When a dolphin finds an underwater mine, it marks the location of the object so it can be avoided by Navy vessels or investigated by Navy divers.

In the future, undersea mines will be hunted by Unmanned Undersea Vehicles (UUV). These vehicles are being developed to patrol for mines in areas where they are suspected to occur.

The performance of a UUV sensor is critically linked to its automatic target recognition (ATR) system. ATR systems use sonar and various image processing techniques to identify and classify unknown objects. While ATR systems have improved in recent years, dolphins still outperform them when it comes to correctly identifying underwater targets.

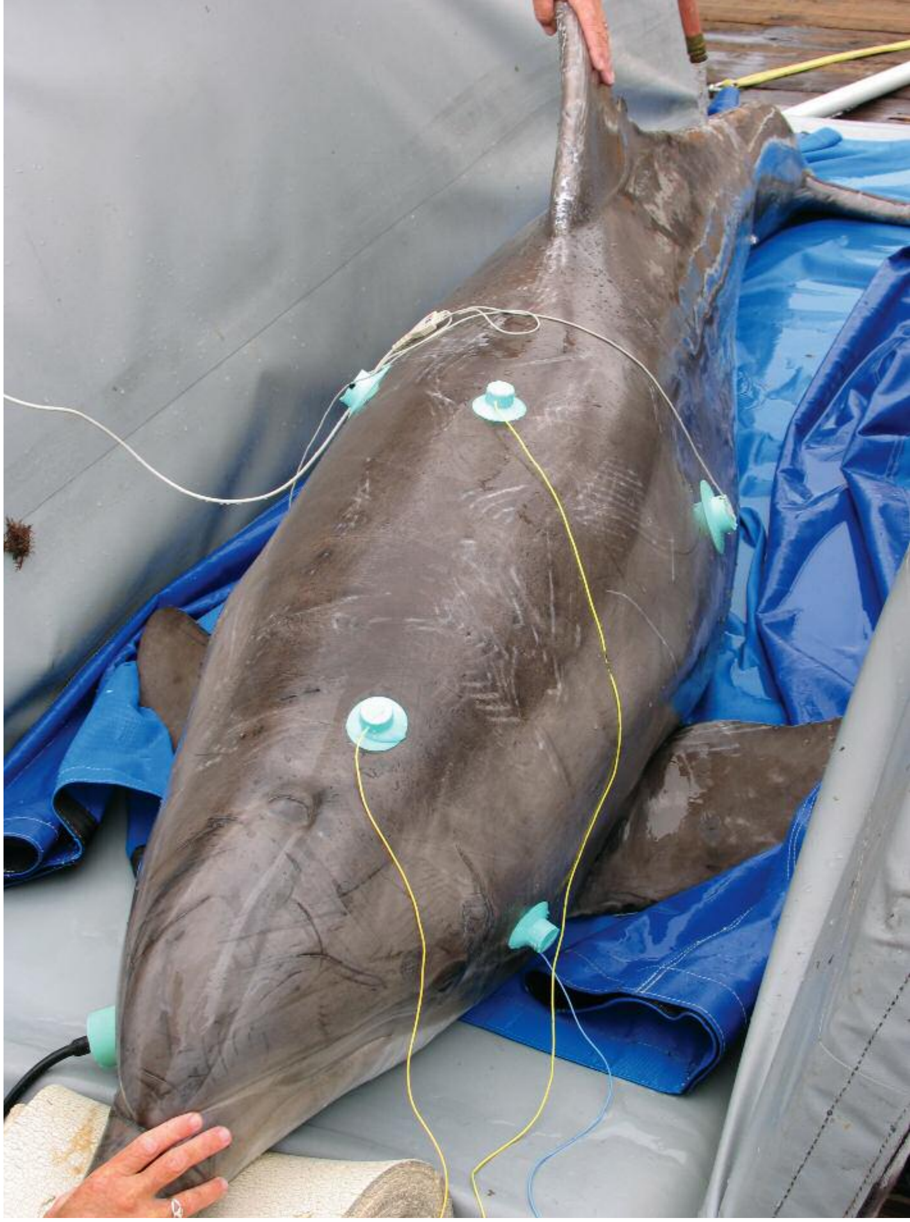
How Echolocation Works

Dolphins echolocate by emitting short-duration sound pulses (called "clicks") and listening to the echoes that return from underwater objects. The time delay between the dolphin's emitted click and its returning echo reveals the target range, while fine-scale differences between the click and echo reveal more specific details about a target's shape and composition. As sound travels from a source it is naturally attenuated—this means that the echoes from underwater objects get smaller as the distance to the object increases. To help compensate for this natural change in echo strength with target range, dolphins have evolved several mechanisms, collectively referred to as "automatic gain control"—similar to the time-varying gain employed with hardware sonars. Based on dolphins' performance in echoic discrimination tasks (reporting minute differences in returning echoes), it seems likely that they perceive the size and shape of targets in geometric terms.

In new research sponsored by the Office of Naval Research (Mine Countermeasures, Acoustics Phenomenology & Modeling Group), Dr. Finneran and his team are combining acoustical, psychophysical, and electrophysiological measurements to understand how dolphins form biological sonar (biosonar) representations. While previous research has been aimed at imitating the acoustic characteristics of dolphin echolocation clicks, this work is directed toward capturing a dolphin's own mental representation of its emitted click patterns and echo delay responses and learning how this information is used by the dolphin to make decisions during echolocation tasks.

Three experiments will be conducted to increase understanding of the characteristics of biosonar representations formed by dolphins:

- Investigating the internal neural representation of the dolphin's own emitted click.
- Determining the limits of echo-delay resolution.
- Examining the feasibility of a signal processing technique called "Independent Component Analysis (ICA)" to isolate neural components associated with echoic signal processing.



A dolphin rests on a foam mat and wears noninvasive surface electrodes during an AEP measurement. Having the dolphin out of the water makes the AEPs easier to measure and allows precise placement of the electrodes. For in-air measurements, jawphones are used to present the sound stimuli to the dolphins. Surface electrodes measure the brain's responses.

Randall Dear

Auditory Evoked Potentials

The first step will attempt to determine whether dolphins may have the same ability as bats to perceive objects in close proximity to each other. Many bats emit a Frequency Modulated (FM) signal, a broadband, tonal signal which enables them to hone in precisely on prey in cluttered environments. Dolphins emit very short-duration, broadband, impulsive sounds that are much different than the longer-duration echolocation sounds used by FM bats.

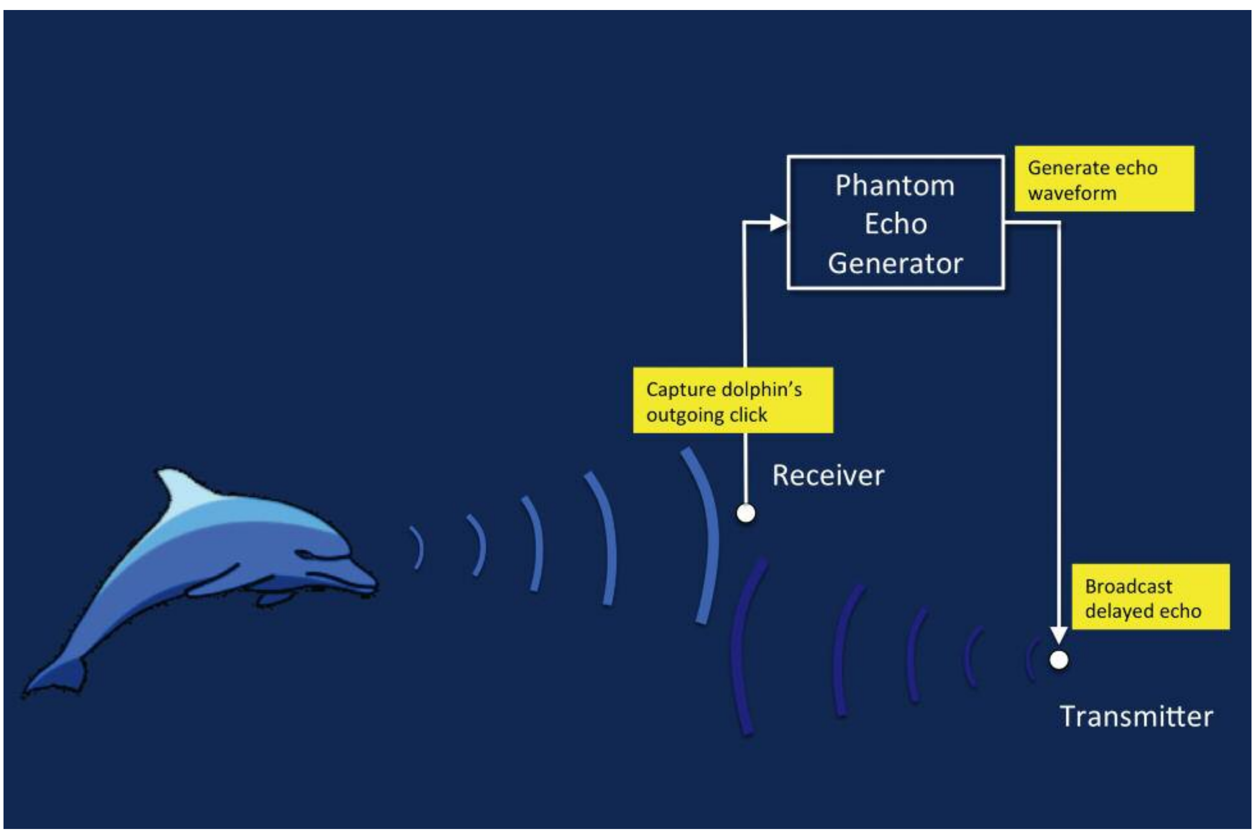
The performance of a UUV sensor is critically linked to its automatic target recognition system.

Dr. Finneran's team has much prior experience measuring the response of the dolphin auditory nervous system to sounds. This technique uses non-invasive surface electrodes to measure small voltages (called auditory evoked potentials (AEP)) generated by the brain and auditory nervous system when an animal hears a sound. In the current research effort, AEPs would be measured and used to determine the frequency content and timing of the dolphin's "self-heard" click at the level of the cochlea. While dolphins do not emit FM signals, frequency-dependent time delays within the cochlea may effectively convert the neurological representations of clicks to FM signals. The AEP method will determine the FM nature of the dolphin's "self-heard" click, which in turn will give researchers an idea about how they might compare to the bat's echolocation process.

Phantom Echoes

Next, an experiment that mirrors a 1990 study with big brown bats will be undertaken. The bat study, headed by J.A. Simmons, utilized complex signals to determine how a bat determines distance to a target and the geometric features of the target.

In this task, a phantom echo generator will be used to simulate echoes from physical targets. The phantom echo generator captures the dolphin's emitted echolocation pulse, creates an electronic echo waveform simulating the echo from a specific target, then broadcasts a delayed, scaled echo back to the dolphin using an underwater speaker. Echoes will be "jittered" or manipulated by alternating echo delays in an attempt to determine how fine the echo delay resolution is in dolphins. The amount



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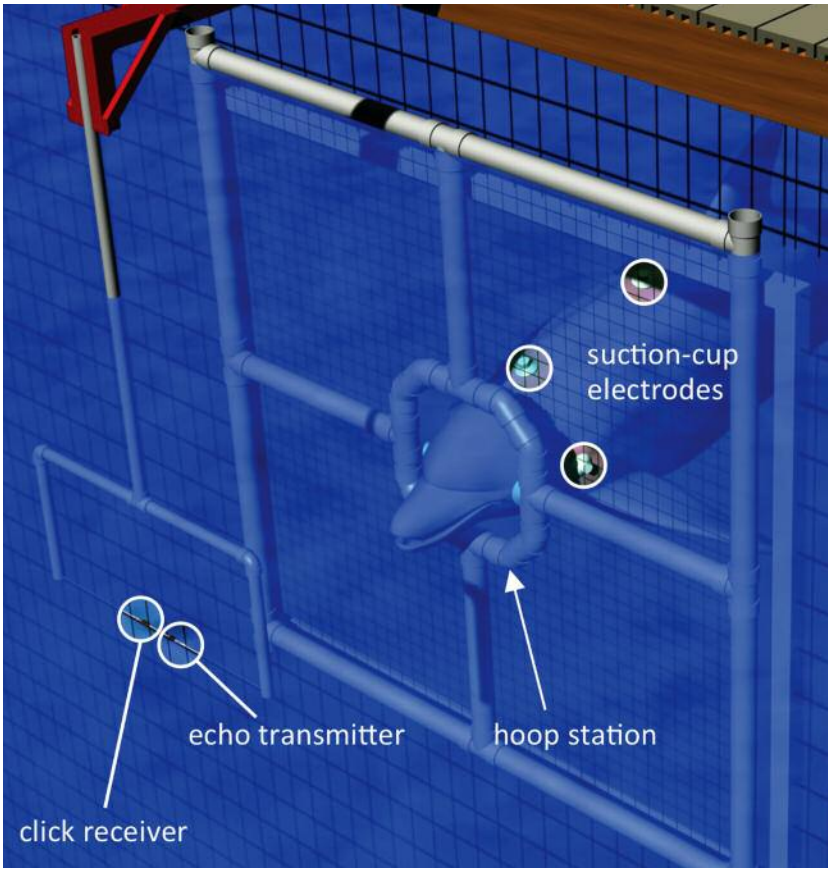
A dolphin wears electrodes in preparation for an underwater AEP hearing test.
James Finneran



Schematic of a dolphin participating in a phantom echo detection task while wearing surface electrodes embedded in suction cups for AEP measurements. The hoop station ensures that the dolphin's position is consistent between trials relative to the sound projector and hydrophone.
James Finneran

of time by which the echoes are jittered would be varied to determine the animal's threshold for determining whether the echoes represent one object or multiple objects. This experiment is intended to determine just how detailed the mental representation is when the dolphin performs an echolocation task. If the animal is able to perceive two distinct, closely placed objects, it's an indication that the dolphin's mental resolution is very small (detailed).

Independent Component Analysis

Next, AEPs will be measured using a multi-electrode array while dolphins perform an echolocation task. The AEP data from the multi-electrode array will then be analyzed using the ICA signal processing technology. ICA technology separates a signal into individual components, which will help researchers identify the spatial locations in the dolphin's brain where various components of the AEP are generated. Identifying these specific

The Basics About the Navy Marine Mammal Program

BEGINNING IN 1959, the Navy began to study the hydrodynamics of the dolphin, with the goal of improving torpedo, ship and submarine designs. Soon the Navy realized that dolphins had other attributes that would make them valuable assistants to Navy divers. Unlike human divers, dolphins are capable of making repeated deep dives without experiencing decompression sickness. They also found that dolphins and sea lions are highly reliable, adaptable and trainable marine animals that could be conditioned to search for, detect and mark the location of objects in the water. Both species are used today to search for lost equipment or vessels on the ocean floor, and to locate and mark sea mines. Over the years, Navy scientists have also studied dolphin behavior and physiology to help learn more about how dolphins are able to swim so fast, dive so deeply, and hone in on underwater objects so precisely.

Today, the Navy cares for, trains, and relies on two species: the bottlenose dolphin and the California sea lion. Both of these species are known for their trainability, adaptability, and heartiness in the marine environment.

For more about the Navy MMP, visit www.public.navy.mil/spawar/Pacific/71500.

TOP: A dolphin looks at the camera as he enters the hoop station in preparation for an echolocation trial.

BOTTOM: A dolphin positioned in the hoop station during an echolocation trial.

Diana Samuelson

anatomical sites within the brain will help researchers better understand echolocation signal processing. Testing will initially begin with the dolphin out of water—the dolphins' outgoing clicks will be recorded using a contact hydrophone placed on the head, and phantom echoes returned to the dolphins using contact transmitters ("jawphones") placed on the lower jaw. This out-of-water experimentation allows for precise and consistent placement of a relatively large electrode array, high signal-to-noise ratios for physiological recordings, and minimization of extraneous noise from subject movement. Further sessions would focus on repeating measurements with an electrode array while the dolphins perform the task under water.

In order for Navy ATR systems to achieve the same performance in complex acoustic environments exhibited by dolphins, their design may need to be re-imagined along biological terms, rather than emulating biosonar using conventional methods. This requires a much greater understanding of how dolphins form biosonar representations and make decisions regarding echoic discrimination and classification. This effort hopes to provide direction toward that goal. ⚓

James Finneran
Space and Naval Warfare Systems Center Pacific
619-767-4098
DSN: 767-4098
james.finneran@navy.mil