Auditory Masking Patterns in Bottlenose Dolphins from Anthropogenic and Natural Noise Sources

Brian K. Branstetter
National Marine Mammal Foundation
2240 Shelter Island Dr., #200
San Diego, CA. 92106
phone: (808) 779-3077  fax: (619) 773-3153   email: brian.branstetter@nmmfoundation.org

Award Number: N000141010500
http://nmmpfoundation.org/

LONG-TERM GOALS

The long-term goals of this project are to better understand and predict auditory masking in odontocetes with realistic, environmental noise types. Current predictions based on Gaussian noise will be improved upon.

OBJECTIVES

The objectives of this effort are to understand and predict how environmental noise (both anthropogenic and natural) affects detection, discrimination, and recognition abilities of bottlenose dolphins. The specific objectives for FY10 were to:

- Record and characterize environmental noise sources (e.g., anthropogenic, weather related, biological),
- Train a dolphin to conduct a psychophysical auditory detection task, and
- Begin estimating masked thresholds (i.e., critical band procedure) with different noise types.

Future objectives for FY11 and FY12 are to:

- Measure discrimination and recognition of auditory signals masked by different noise types,
- Develop and test hypotheses to describe the auditory processing governing the resulting masking patterns, and
- Develop predictive quantitative models to describe masking with environmental noise.

APPROACH

One feature of environmental noise that has a profound effect on a noise source’s ability to mask a signal is across-channel envelope coherence. When energy across different frequency bands is coherently modulated, a release from masking occurs, known as comodulation masking release or...
CMR [Nelken et al., 1999, Branstetter and Finneran, 2008]. Although terrestrial noise tends to be largely comodulated, the extent to which underwater noise is comodulated is unknown. We plan to acquire and analyze underwater noise sources by building on the statistics developed by Nelken et al. (1999), as well as developing novel statistics where needed. An attempt will be made to identify relationships between statistical features of the physical sound and masked thresholds.

Our location adjacent to Navy Submarine Base San Diego and our close proximity to North Island Naval Air Station gives us unique access to a variety of natural and anthropogenic noise sources. In addition, noise samples will be acquired through a collaborative effort with scientists currently collecting noise samples in other parts of the world.

Behavioral threshold methods developed at SSC San Diego (e.g., [Finneran et al., 2005]) allow thresholds to be obtained rapidly (i.e., less than four minutes). Behavioral thresholds are measured using a psychophysical technique, such as modified up/down adaptive staircase.

The procedure for estimating masked thresholds is identical to a standard behavioral hearing test except masking noise is played continuously during the threshold estimation procedure. Noise bandwidth will vary depending on the frequency of the signal. For example, for a 10 kHz tone signal, noise bandwidths will be 0.25, 0.5, 1, 2, 4, and 8 kHz. In addition to noise recorded from environmental sources, Gaussian noise of equal pressure spectral density and bandwidths will be used for comparison purposes. One of the primary advantages of a band-widening paradigm over a critical ratio paradigm (tone detection in broadband noise) is that the pattern of masking can reveal clues to the type of auditory processing taking place.

WORK COMPLETED

Noise acquisition
In addition to noise samples recorded in San Diego Bay, we have collaborated with Marc Lammers and Jenifer Miksis-Olds (Award number N000140810391) who have provided us with field recordings of noise associated with marine mammal environments. The following noise types have been acquired:

*Natural*: rain, thunder, wind / waves, ice squeaks, snapping shrimp, humpback whale chorus (Hawaii), whale chorus (Alaska), pinniped chorus (Alaska).

*Anthropogenic*: pile saw, small motor boat, tug boat c-tractor, vibratory hammer.

*Computer generated* (for comparison purposes): Gaussian noise, comodulated noise.

Example spectrograms of acquired noise files are presented in Figure 1. A Matlab program to analyze noise statistics related to auditory masking is currently in development.
FIG 1. Noise samples with different time-frequency patterns. Rain noise (A) appears to have a Gaussian like structure while motor boat (B) and pile saw (D) have noise limited to multiple discrete frequency bands. Ice Squeaks (C) are frequency modulated.

Training dolphins to perform a psychophysical hearing test
One dolphin (SAY) was trained to perform a psychophysical hearing test and another dolphin (BLU) had been previously trained in the tasks. Completion of training for SAY was rapid (two weeks) and preceded the acquisition of environmental noise samples. As a result, we completed two experiments (initially planned for FY2011) to test two hypotheses related to masking release in comodulated noise (see Masking release mechanisms below). Estimating masked thresholds with environmental noise began on Sept 9, 2010.

Masking release mechanisms
We conducted two experiments to determine which acoustic features of comodulated noise produce CMR. One hypothesis states that temporal envelopes must be coherent across frequency regions (i.e., across-channel envelope coherence) for a release of masking to occur. We tested this hypothesis by dividing wideband masking noise (Gaussian and comodulated) into three noise bands (FIG 2A): a masking band 1000 Hz wide, centered on the 10 kHz signal and two flanking bands (6 kHz to 9 kHz; 11 kHz to 14 kHz). The degree of across-channel envelope coherence was manipulated by systematically delaying the masking band in time (FIG 2B). If across-channel envelope coherence is necessary for CMR, then greater masking band delays should result in a disruption of the CMR effect (i.e., increased masked thresholds).
The second hypothesis states that with amplitude modulated maskers, a release from masking can occur if the animal listens “within-the-valleys,” or within the short time periods where the noise is lower in amplitude. Depth of amplitude modulation (i.e., valley depth) was manipulated with the following equation:

\[ Env(t) = h(t)A + (1-A) \]

Where \( h(t) \) is the Hilbert envelope of comodulated noise, and \( A \) is the amplitude of the envelope where \( A = 1 \) is equivalent to 100% modulation depth. \( Env(t) \) was then multiplied by Gaussian noise resulting in different waveforms that shared the same temporal envelope structure but varying degrees of modulation depth. (FIG 3) We hypothesized that decreasing the modulation depth would lead to a threshold increase.
RESULTS

At least two different auditory mechanisms can account for CMR in dolphins: (1) across-channel processing of envelope information and (2) within-channel valley listening. FIG 4 demonstrates that the dolphin auditory system compares temporal envelopes across frequency regions. When these envelopes are out of phase (i.e., larger delays), the dolphin’s auditory system has difficulty segregating a tonal signal from the background noise, resulting in a threshold increase. FIG 5 demonstrates that the dolphin’s auditory system also exploits relatively “quiet moments”, or temporal valleys, to enhance signal detection capabilities. Neither mechanism can be used with Gaussian noise maskers.

FIG 4. Results from the phase delay experiment. Masking band delay for Gaussian noise had no effect on signal thresholds. For comodulated noise, delays less than 1 ms had no effect on signal thresholds. Delays from 1 to 10 ms produced an increase in thresholds. Delays greater than 10 ms no longer increased thresholds.

FIG 5. Results from the modulation depth experiment. Modulation depths greater than 90% produced a monotonic decrease in thresholds. The data point at 0% modulation depth is Gaussian noise with no amplitude modulation envelope.
IMPACT/APPLICATIONS

When detecting signals in noisy environments, odontocetes can exploit noise-related, time-domain information, resulting in a release from auditory masking. At least two mechanisms (across-channel envelope comparison and within-valley-listening) govern this ability. Environmental noise is often amplitude-modulated, suggesting tone detection in natural noise may be governed by the same auditory mechanisms as CMR. A better understanding of CMR mechanisms and how they are related to environmental noise is needed. Predicting auditory masking has historically relied on metrics related to the spectral density of the masking noise (ignoring time-domain information) and extrapolations made from masking studies which employed Gaussian noise. This approach is incomplete and likely overestimates auditory masking for non-Gaussian noise (such as noise often found in real aquatic environments). Accurate predictions of auditory masking should include time-domain statistics specific to the degree of across-channel envelope coherence of noise and modulation depth of noise.

REFERENCES


PUBLICATIONS