LIVING MARINE RESOURCES PROJECT 50

Loudness Perception in Killer Whales (*Orcinus orca*); Effects of Temporal and Frequency Summation

NEED

Relationship Between Perceived Loudness of a Signal and Signal Duration

To understand the potential effects of sounds created by Navy training activities on marine mammals, the Navy needs information not only on physiological effects (i.e., temporary threshold shift, permanent threshold shift), but also how sounds can influence marine mammals' behavioral response. Both context and perceived components of the sound, rather than the physical characteristics alone, may contribute to response. One perceptual component of sound is perceived loudness and one factor that may lower perceived loudness, and therefore reduce the potential for a behavioral response, is the duration of the sound or signal.

In addition, the relative loudness of multicomponent signals will be compared to pure tone (i.e., single frequency) signals to determine if summation across the frequency spectrum occurs. Because current auditory weighting functions are based on pure tone, long-duration signals, and may not generalize to pulsed tones or broadband sounds, the data from this effort may provide modifications for the weighting functions.


A killer whale positioned on a stationing device while participating in a psychophysical hearing test.

SOLUTION

This project is investigating perceived loudness in killer whales using a multi-pronged approach:

1. Determine the effect of signal duration on response latency
2. Determine the effect of signal duration on detection thresholds
3. Determine the subjective loudness of short duration signals compared to long-duration signals.

METHODOLOGY

The project team is working with three trained killer whales (*Orcinus orca*) with good species-representative hearing. Due to their large size and increased sensitivity to lower-frequency sounds, killer whales are currently the best "hearing surrogates" for other large odontocetes such as beaked whales and sperm whales, where high-quality behavioral audiograms do not exist. Testing will be done at Sea World in a quiet and isolated pool, which will support an exceptional amount of experimental control over the testing environment and acoustic stimuli.

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The effort is organized around three experiments, discussed below.

Experiment 1: Detection thresholds and response latency as a function of signal duration and frequency

The goal of the first experiment is to measure audiograms (i.e., detection thresholds as a function of frequency) for short duration signals (i.e., less than the temporal integration time) and estimate weighting functions for different signal durations.

Audiograms will be measured using a standard psychophysical method, which is the most accurate method for testing hearing. A go, no-go response procedure, coupled with a one-down, one-up adaptive staircase procedure will be used to estimate detection thresholds at the 50% correct level. Separate audiograms will be measured for each signal duration (e.g., 25 ms to 1000 ms) resulting in a family of audiograms or an audiogram function with an extra parameter for signal duration. Duration-specific audiograms can then be used to estimate auditory weighting functions with an additional parameter for signal duration.

Equal latency contours can be estimated from the same data collected during the threshold estimation procedure. By analyzing response latency as a function of signal duration and signal level, equal latency contours can be constructed. The frequency tests will be focused within 1-octave above and below best hearing (34 kHz), although the project will try to test the full range of hearing. For this testing, priority will be first to lower frequencies (where killer whale communication and Navy sonar occur) and then to higher frequencies.

Experiment 2: Subjective loudness comparison for different duration signals

This experiment will be a direct test (validation) of the duration-specific weighting functions from Experiment 1. The project team will use a two interval, two-alternative, forced-choice paradigm in which two sounds will be presented to a killer whale, with a short silent interval between them. The whale's task will be to determine which sound (the first or second) is perceived louder by pressing a corresponding paddle (i.e., paddle one if the first sound is louder or paddle two if the second sound is louder). Within each session, the frequency of the two tones will be the same and held constant. One of the sounds, called the reference sound will have a fixed duration of (e.g., 1000 ms) and a fixed level (e.g., 30 dB sensation level). The other sound, called a comparison sound, will have a fixed duration (e.g., 100 ms) for the session but the SPL will vary on a trial-by-trial basis. This procedure will be repeated for comparison signal duration from 25 ms to 1000 ms within each frequency.

Because data collection for this paradigm will likely require more time and effort, testing of only a subset of frequencies is currently planned to validate the results from Experiment 1. The frequencies tested will be within 1-octave above and below best hearing (34 kHz). If possible, however, the team will try to test the full range of hearing. As in Experiment 1, priority will be given to lower frequencies (where killer whale communication and Navy sonar occur) and then to higher frequencies.

Experiment 3: Loudness of multicomponent signals

This experiment will test how well auditory weighting functions predict perceived loudness of broadband sounds and will provide data to modify weighting functions based on signal bandwidth. Testing harmonics and bandwidth is important to the detection threshold and indicating how the harmonic components in Navy sonar signals may be perceived as louder than simple model predictions from auditory weighting functions. In addition, the experiment will determine how the killer whale's auditory system sums harmonic components across frequencies resulting in an increase in perceived loudness.

The same two-alternative forced choice paradigm from Experiment 2 will be implemented in Experiment 3. However, the loudness comparison will be between a reference tonal signal (fundamental frequency only) and a comparison multi-component signal (fundamental frequency plus harmonics). The number of harmonics will be an independent variable (rather than duration as in Experiment 2). The relative levels of the harmonics in the comparison sound will all be a constant sensation level (e.g., all harmonic components may be at 30 dB sensation level). The frequencies tested will represent Navy sonar signals, which have a strong frequency overlap with killer whale social signals.


Killer whale.

SCHEDULE

All whale training will be completed in 2022 as well experiment 1 data collection. Data collection for experiments 2 and 3 will be initiated during 2022 and completed in 2023.

NAVY BENEFITS

The data from this project will help to allow the U.S. Navy to complete its mission while protecting at risk marine mammals by improving auditory weighting functions used in environmental criteria. Because the current auditory weighting functions are derived from long-duration pure tones and may not generalize to other types of sounds, developing duration-dependent, and bandwidth-dependent, auditory weighting functions will support perceived loudness estimations for a broad range of signals. Defining the relationship between perceived loudness and signal duration for killer whales will also provide data for other large odontocetes such as beaked whales and sperm whales, because killer whales are currently the best hearing surrogate for this group.

TRANSITION

This study will provide the necessary data to modify current auditory weighting function to include both pulsed tones and broadband sounds. Results will be provided in project reports and in manuscripts to be submitted for peer-reviewed publication. The data will support the Navy at-sea environmental compliance community in environmental criteria development.

ABOUT THE PRINCIPAL INVESTIGATOR

Brian Branstetter is a research scientist at the National Marine Mammal Foundation. Dr. Branstetter's research interests focus on marine mammal psychoacoustics and cognition, echolocation, auditory masking, whistle production and perception, and vigilance in dolphins. He also works on characterizing anthropogenic noise in marine environments. He earned his Ph.D. from the University of Hawaii, Manoa.