

## **New Approaches to Studying Auditory Processing in Marine Mammals**

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### **LONG-TERM GOALS**

The goals of the proposed effort are to enhance our understanding of the manner in which marine mammals process and respond to complex, real-world sounds by developing new experimental approaches to studying marine mammal auditory perception. The results of this study would provide new methodologies to enable the study of more complex features of auditory perception such as subjective stimulus similarity/dissimilarity and auditory template matching.

### **OBJECTIVES**

The study aimed to develop novel techniques, based upon previous studies with birds (Dooling and Okanoya, 1995), for studying auditory perceptual similarity in a California sea lion (*Zalophus californianus*) and a bottlenose dolphin (*Tursiops truncatus*). It was proposed that subject response time (RT) would provide a useful metric of perceptual similarity.

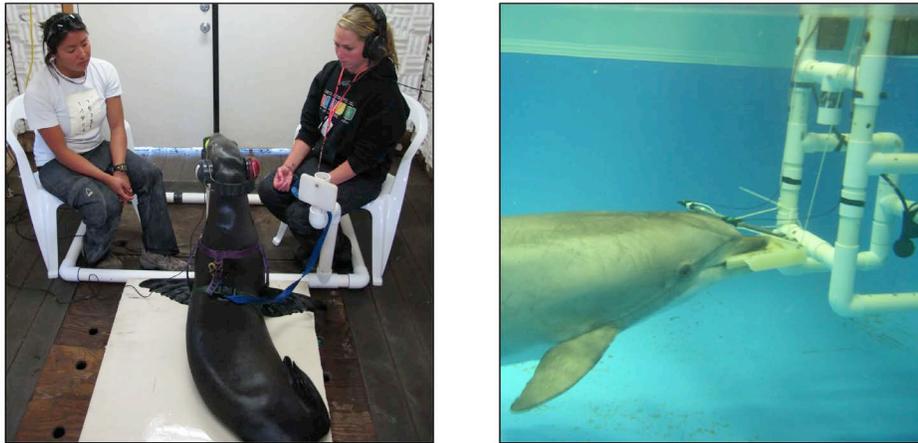
The specific objectives were to (1) train the subjects for a task in which a conditioned response was provided upon detection of a change in a repeated background stimulus (i.e., an auditory discrimination task), (2) use subject RTs measured in a pure tone discrimination task to demonstrate the effectiveness of the method for describing perceptual categorization, and (3) demonstrate the effectiveness of the method for studying the discrimination of complex real-world sounds.

### **APPROACH**

A psychophysical task is designed to study the auditory discrimination capabilities of California sea lions and bottlenose dolphins. For this task, a subject remains attentive while a background sound is presented repeatedly, and presents a conditioned response upon detecting any change from background conditions (Figure 1). A sea lion is trained to wear a pair of headphones in a quiet room and to press a paddle upon the detection of a change, and a dolphin is similarly trained to station in a pool and to whistle upon detecting a change. Two types of trials are presented: *change trials* in which a background tone alternates with a “change” tone, and *catch trials* in which the background is repeated

without a change. Correct responses (i.e., responding in the presence of a change or withholding response when no change is present) are both rewarded with fish reinforcement.

Initial sessions require the subjects to discriminate between pure tones that vary only in their sound pressure level (SPL). Subject response time (RT) is measured for all trials by measuring the delay between the onset of a change in the background and the onset of the conditioned response. These data are analyzed in order to determine if RT is a reliable indicator of the subjective difficulty of discriminating stimuli. Secondary sessions with the sea lion use the procedure described above and require the subject to discriminate between complex natural stimuli.



***Figure 1. A California sea lion (left) and a bottlenose dolphin (right) participating in an auditory discrimination task. Subject RTs were determined by measuring when the instants when the sea lion moved to press the paddle and when the dolphin produced the whistle response.***

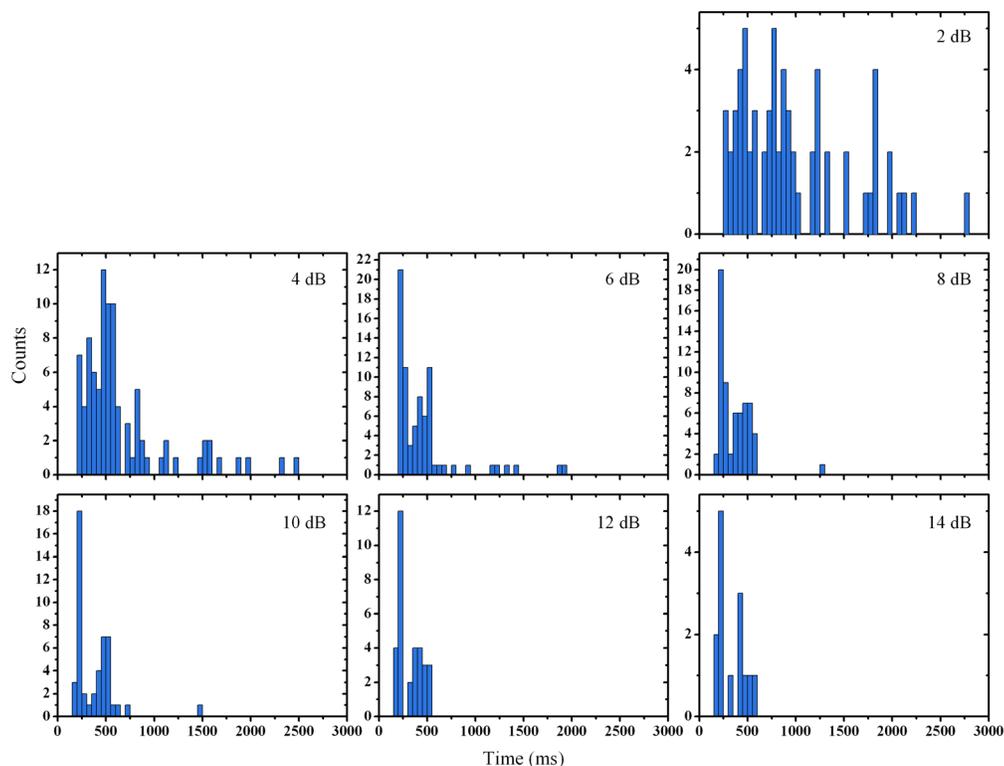
## **WORK COMPLETED**

The sea lion and the dolphin were trained for the discrimination task, and custom software was designed to produce the required stimuli and record subject RTs. The two subjects participated in experimental sessions in which they were required to discriminate between tones that were identical in terms of frequency, duration, and envelope, but differed in terms of SPL. Data collection comprised individual sessions in which each SPL was compared to a standard background stimulus of constant SPL. Each SPL included in the experiment acted as the background in successive sessions, and a test matrix was completed when each SPL had acted as the background once. Data from a matrix was therefore composed of the subjects' discrimination RTs for all possible SPL comparisons. These data were then analyzed to determine the relationship between RT and perceptual similarity. Following testing with pure tones, the sea lion was trained to discriminate between California sea lion vocalizations.

## **RESULTS**

Training of the behavior was achieved relatively rapidly; the performance of both subjects was sufficient for data collection after one to two months of training. For initial analysis of the data from

each subject, all trials of equal SPL difference were pooled together. The sea lion's correct-detection percentage for change trials ranged from 94-100% when the SPL difference was 4 dB or greater. For comparisons with a 2-dB difference, performance was at 58% indicating that this amplitude difference was near the sea lion's discrimination threshold at 8 kHz. This result was similar to discrimination thresholds previously obtained with California sea lions (Moore and Schusterman, 1976), and suggested that the data were representative for this species. Data for the dolphin were similar; performance was between 93-100% at amplitude differences greater than 4 dB, and degraded to 77% at 2 dB. Histograms of RTs were generated for the data pooled according to SPL difference (Figure 2). The histograms were generally positively skewed, a feature that is characteristic of RT data. The central tendencies of the histograms decreased with increased difference between the SPLs of tones; thus, shorter RTs were associated with higher correct-discrimination probabilities and were indicative of larger subjective difference between tones.



**Figure 2. Distributions of California sea lion response times for all possible amplitude differences in a pure-tone discrimination study. Amplitude differences are given in the upper right of each plot. Data in each plot are pooled from all trials with a particular difference in amplitude (e.g., trials comparing 54 dB with 56 dB are pooled together with those comparing 60 dB with 62 dB, 50 dB with 52 dB, etc.)**

Average RT matrices were constructed for both subjects, with each cell corresponding to the mean response time for a given background and change SPL. Each matrix was then “folded” such that cells corresponded to the mean RTs for all comparisons between two SPLs (Figure 3). Matrices for both the

sea lion and the dolphin were similar in that response latencies generally decreased with increasing difference between the SPLs of the two tones.

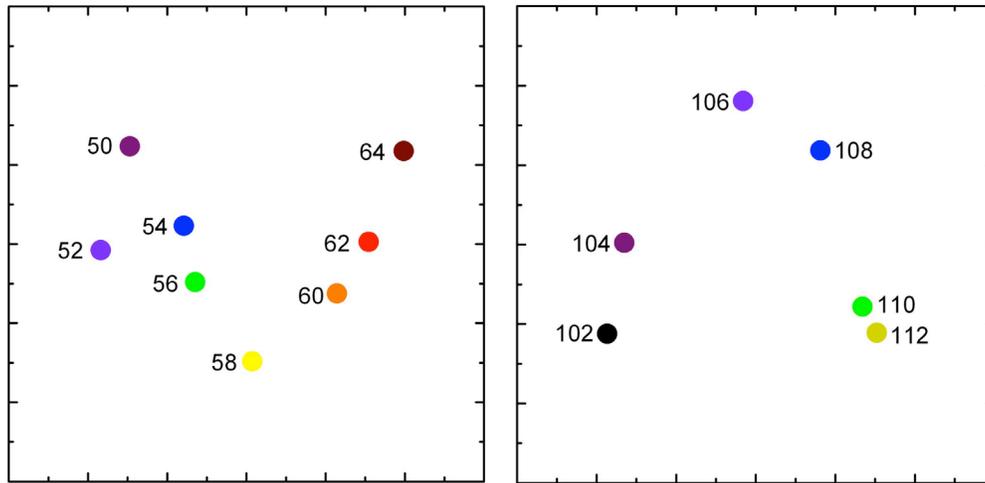
The RT data from the subjects' matrices were analyzed using multidimensional scaling (MDS) analysis. Using RT as a proxy for perceptual similarity, an MDS analysis algorithm was used to create 2-dimensional "perceptual maps" where subjectively similar stimuli were located in relatively close proximity to one another (Figure 4). Tones with similar SPLs were located in close proximity to each other in the perceptual maps. This confirmed that the subjects perceptually organized tones based on amplitude. The maps were similar to those obtained with humans and birds in previous experiments (Dooling *et al.*, 1987), and indicated that the methods from this study are suitable for studying subjective perception of acoustic stimuli in sea lions and dolphins.

		Tone 2 amplitude (dB re 20 $\mu$ Pa)							
		50	52	54	56	58	60	62	64
Tone 1 amplitude (dB re 20 $\mu$ Pa)	50	-	-	-	-	-	-	-	-
	52	875	-	-	-	-	-	-	-
	54	872	891	-	-	-	-	-	-
	56	580	921	1048	-	-	-	-	-
	58	342	454	515	970	-	-	-	-
	60	406	339	480	669	1036	-	-	-
	62	332	364	406	463	442	1211	-	-
	64	333	311	364	367	343	537	807	-

		Tone 2 amplitude (dB re 1 $\mu$ Pa)					
		102	104	106	108	110	112
Tone 1 amplitude (dB re 1 $\mu$ Pa)	102	-	-	-	-	-	-
	104	1115	-	-	-	-	-
	106	739	1089	-	-	-	-
	108	642	740	1148	-	-	-
	110	624	728	702	992	-	-
	112	585	597	617	776	889	-

**Figure 3. Mean response times (in msec) for a California sea lion (left) and a bottlenose dolphin (right) performing a tonal discrimination study. The mean response time is calculated by pooling all response times for a specific amplitude comparison (e.g., the “50 dB/52 dB” cell includes data from trials with a 50 dB background tone and a 52 dB change tone and vice versa.)**



**Figure 4. Two-dimensional “perceptual maps” of tonal stimuli, varying only in amplitude, for a California sea lion (left) and a bottlenose dolphin (right). The maps were created by analyzing mean response times (Figure 3) using a multidimensional scaling algorithm. Numbers next to each point represent the amplitude of the tones (in dB re 20  $\mu$ Pa for the sea lion, dB re 1  $\mu$ Pa for the dolphin). Points that are located in close proximity were perceived by the subjects as being similar.**

Following completion of the pure tone discrimination portion of the study, the sea lion was trained to discriminate between complex natural stimuli: vocalizations recorded from a number of individual California sea lions. Transfer from the pure-tone discrimination task with to one using vocalizations was completed in less than a month, suggesting that the methods used in this study represent a robust and easily trained procedure for studying the discrimination of simple and complex sounds.

## IMPACT/APPLICATIONS

The similarity of the results to those previously obtained with birds, and humans suggest that the methods developed here are a valid means of studying the subjective perception of acoustic stimuli in marine mammals. These methods are easily trained with captive subjects, and they appear to be readily generalized to a variety of stimuli, from simple pure tones to complex real-world sounds. The ease of training these methods makes them an attractive option for studying the perception of complex acoustic stimuli in marine mammals, an aspect of auditory processing that is difficult to assess using procedures such as traditional threshold audiometry.

## RELATED PROJECTS

None.

## REFERENCES

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