

Discrimination of pure-tone intensities by the California sea lion*

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On the basis of previous behavioral experiments on sound localization under water along with sound-skull measurements in water, it was hypothesized that the California sea lion (*Zalophus californianus*) is capable of discriminating an intensity difference of approximately 3 dB at 16 kHz. The present experiment confirmed this hypothesis by means of a series of behavioral psychophysical experiments.

Subject Classification: [43]80.50, [43]80.60; [43]65.50, [43]65.75.

INTRODUCTION

The purpose of this study was twofold. First, we tested the hypothesis put forward by Moore and Au¹ that at 16 kHz the California sea lion (*Zalophus californianus*) is capable of discriminating an intensity difference underwater of 3.0 (± 0.4) dB. This hypothesis was derived from a series of behavioral experiments on minimum audible angle (MAA) coupled with sound-skull measurements in water to determine the role of sound shadowing by a sea-lion head.^{1,2} Secondly, we wanted to find out whether a sea lion that persistently biased its responses by making a low rate of false alarms (thus maintaining a relatively strict response criterion) in an *absolute* threshold task³⁻⁵ would bias its response in the same direction in a *difference* threshold task.

I. METHOD

The experimental animal (Sam) was an 11-to-12 year old male *Zalophus*. Sam had previously been used in several underwater acoustic detection tasks⁵ and most recently had been trained to bark a different number of times to tones of different intensities.⁶ Sam's reward feedings were supplemented after testing to a daily total intake of approximately 11 kg of herring. Testing began each morning with Sam usually 18-20-h food deprived.

The experiment was conducted in a 3.5 × 11.1 × 1.2-m above-ground concrete pool. One end of the pool contained the testing platform which housed the test equipment, observation port and the experimenters (see Schusterman *et al.*⁵ for details). The 160 kHz pure tone was introduced into the water by a F-50 transducer calibrated by the Underwater Sound Reference Division, Naval Research Laboratory, Orlando, FL. Alongside of the transducer was a 150-W flood lamp. Both were mounted on 1.3-cm steel pipe which held them in a fixed position above the bottom of the pool. The water level of the pool was 91.4 cm, and during the testing, the transducer was 43.2 cm from the bottom and 172.7 cm from the sides of the pool. The sea lion was required to place his head on a head stand that positioned him at a distance of 3.1 m directly in front of the transducer, and 43.2 cm above the pool bottom. An Atlantic Research hydrophone (LC-50) monitored the underwater sounds.

Schusterman, Balliet, and Nixon⁷ provide a full description of the equipment controlling the experimental

contingencies and amplifying, attenuating, monitoring, and measuring acoustic signals. A signal of 16 kHz was used in the present study and detailed measurements of the signal relative to ambient noise can be found in Schusterman *et al.*⁵

Sam was tested daily in one morning session which began when the experimenter placed the head stand in the pool. Each session started with 20 warm-up trials consisting of large intensity-difference (ΔI) tone pairings followed by 200 "threshold" trials, and was terminated with 20 trials in which the ΔI of the tone pairings were again made large.

The paradigm used throughout testing was a yes-no signal detection task with trial-by-trial feedback. Sam was trained to identify a 16-kHz tone as the louder or softer of a stimulus pair, each stimuli being compared to an internal sample maintained by feedback (this format has also been used to study intensity discrimination in humans by McGill and Goldberg⁸). A trial began when Sam assumed a fixed position on the head stand. A warning light came on for 3.5 sec during the last second of which a tone pulse sounded; the light and tone terminated simultaneously. A "correct response" to the softer tone was silence or no vocalization and a "correct response" to the louder tone was a barking vocalization. Following the termination of the light and tone, Sam was trained to swim off the head stand and push a paddle signaling the end of a trial. The animal was reinforced with a piece of cut herring following a paddle press if it emitted a correct response (see Schusterman,⁶ for greater detail on the training of these behaviors).

A modified method of limits similar to the "staircase method" was used to obtain all ΔI measurements. A stimulus intensity pair was presented randomly in blocks of ten trials, five louder and five softer trials. If the animal identified seven out of the ten trials correctly the stimulus pair was changed.

Since this was the first attempt to gather intensity-discrimination data on any pinniped species, a series of preliminary threshold experiments were performed to determine the effects of stimulus-presentation strategy on discrimination ability. Three different stimulus-presentation stratigems were tested using a random block over sessions design. The three experiments consisted of (a) fixing the intensity of the standard alter-

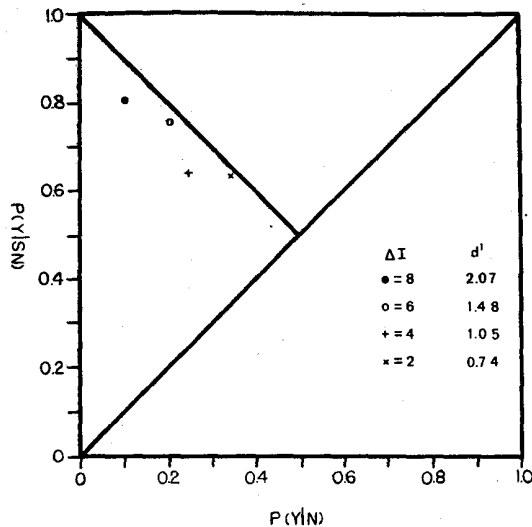


FIG. 1. Signal-detection plot for discrimination of auditory intensities by a California sea lion.

native of each intensity pair at the most intense level (117 dB *re* 1 μ Pa) and increasing the comparison stimulus from the least intense signal level (97 dB *re* 1 μ Pa) in 2-dB increments; (b) the reverse of a, fixing the intensity of the standard alternative of each intensity pair at the least intense level and decreasing the intensity of the comparison from the most intense level in 2-dB steps; and (c) the "collapse method," starting with the pairing of the 117- and 97-dB signal levels and symmetrically reducing the louder and increasing the softer member of the pair by 2 dB until the smallest ΔI between the standard and the comparison was 2.0 dB. The stimulus pair intensities used for the intensity-discrimination tasks are presented in Table I.

II. RESULTS AND DISCUSSION

The results of the preliminary threshold experiment indicated that at $d' = 1.0$, the corresponding ΔI 's for stimulus-presentation strategies (a), (b), and (c) were 7.60, 6.82, and 4.75 dB, respectively. Since method (c), the collapse method, yielded the smallest threshold value, this stimulus-presentation method was used for the final threshold estimates.

During the course of the threshold estimates, it became apparent that sea-lion Sam steadily improved his

TABLE I. Stimulus intensity pairs for the three different stratigems (dB *re* 1 μ Pa).

ΔI (dB)	Series (a)		Series (b)		Series (c)	
	louder	softer	louder	softer	louder	softer
20	117	97	117	97	117	97
16	117	101	114	97	115	99
12	117	105	109	97	113	101
10	117	107	107	97	113	103
8	117	109	105	97	111	103
6	117	111	103	97	111	105
4	117	113	101	97	109	105
2	117	115	99	97	109	107

TABLE II. Results for the first ten days of testing versus the second ten days of testing.

ΔI (dB)	First ten days of testing			Second ten days of testing		
	Number of trials	% correct	d'	Number of trials	% correct	d'
2	130	54.6	0.23	240	62.9	0.74
4	250	64.4	0.61	260	69.6	1.05
6	240	69.1	0.84	200	77.0	1.48
8	180	76.6	1.24	140	83.5	2.07
10	90	80.0	1.45	50	98.0	2.34

performance. A comparison of Sam's performance for the first ten days of threshold testing and the second ten days of testing, which is shown in Table II, clearly indicated an improvement in his ability to detect small intensity differences. For this reason, the difference threshold (DL) estimate was based only on the last ten days of testing.

Figure 1 is a signal-detection plot of the last ten days of testing and shows each of the data points obtained as a function of decreasing the ΔI of the tone pairs by 2, 4, 6, and 8 dB. A systematic decrease in intensity difference resulted in a systematic decrease in the sea lion's discrimination ability. This function is unambiguously shown as the data points fall along the minor diagonal, starting from the upper left-hand corner (perfect detection), and gradually approach the major diagonal (chance detection). Since the signal-detection plot indicated that the possible types of "error" (false alarms and misses) are equally likely, there is no indication of response bias by sea-lion Sam in a difference threshold task as compared to his repeated manifestation of biasing affects in previous absolute threshold tasks.^{3,5} Unlike the training for the latter tasks we made sure in the present study not to arrange reinforcement contingencies which might result in response bias. Apparently, the original discriminative stimuli and reinforcement contingencies under which an animal is trained, continue to exert strong control over response criterion and one way to change the animal's response criterion is to change either the discriminative stimuli, the signal probabilities, or the payoff matrix.

The d' values, as shown in Fig. 1, reflect the changes in the intensity differences. The d' 's are indices of differential sensitivity and the larger the value, the greater the degree of sensitivity.⁹ Since the sea lion showed no response bias, an intensity difference yielding a $d' = 1.0$ may be used as an estimate of the DL for tone intensity.¹⁰ This technique results in sea-lion Sam showing a DL of 3.689 dB. This value is only slightly above the intensity discrimination necessary for intensity cues to play a major role in underwater sound localization by *Zalophus*¹ for frequencies above 4 kHz.

When an additional 1972 trials at $\Delta I = 4.0$ dB (obtained from ongoing research concerned with generating signal-detection plots in an intensity-discrimination task at 4.0 dB) are added to the 260 trials at $\Delta I = 4.0$ dB presented in Fig. 1, a $d' = 1.0$ results in a DL of 3.19 dB, indicating that the sea lion is capable of discriminating intensity differences of approximately 3.0 dB. Of course these findings do not demonstrate that a sub-

merged sea lion uses intensity cues to localize underwater sound sources, but the results do offer previously lacking behavioral evidence that this is a viable acoustic cue available to the sea lion underwater.

Unfortunately, only a limited amount of information exists regarding this sensory capability in other marine mammals. Evans,¹¹ in a review of the literature, reports comparative discrimination performance, in an echolocation task, for the Bottlenose porpoise (*Tursiops truncatus*) and for the Amazon-River dolphin (*Inia geoffrensis*) using submerged targets of varying reflective signal strengths. Inspection of this data suggests that both delphinids could detect (at 70% correct responses) a reflective signal difference of about 1.0 dB. One should expect both *Tursiops* and *Inia* to exhibit a smaller DL for intensity than the sea lion since both species are known to possess a sophisticated echolocation system.

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