Underwater Visual Discrimination
by the California Sea Lion

Ronald J. Schusterman
Winthrop N. Kellogg
Charles E. Rice

Underwater Visual Discrimination by the California Sea Lion

Abstract. *Two captive sea lions (Zalophus californianus) presented with a series of size-discrimination tasks showed preferences for the smaller of two targets and gave virtually errorless performances despite changes in the form and relative size of the targets. Further tests revealed that they were capable of discriminating a size-difference ratio as small as 1.06:1.*

Seals and sea lions emit series of short pulses while apparently searching for underwater objects—usually food (*1*). These pulses appear to be similar in many ways to the sonar clicks of the porpoise as described by Kellogg (*2*) and are considered by Poulter (*3*) to be ideally suited for the echo detection of objects under water. If seals and sea lions do have a superior sonar system, then a question arises as to the role that underwater vision plays in the abilities of these animals to navigate and find food. Although anatomical and physiological evidence suggests that most pinnipeds have good underwater vision (*4*), there have been no previous experiments dealing with the sea lion's visually guided behavior in an underwater environment. We have, therefore, studied the ability of sea lions to differentiate among targets of various sizes while monitoring their underwater sounds.

All testing was conducted in an oval tank constructed of redwood and measuring 4.57 m by 9.14 m and 1.83 m deep (Fig. 1). The interior of the tank was painted white; during testing it was filled with 81.8 kiloliters of fresh water, and animals could be observed and photographed by means of six windows spaced around the perimeter of the tank. A hydrophone (*5*) was usually available for recording and monitoring underwater sound signals.

We used two female California sea lions (*Zalophus californianus*), which, at the time of their arrival at our laboratory (26 February 1964) had been in captivity for approximately 3 weeks; each weighed 25 kg. They were approximately 17 to 20 months old when training was initiated. The sea lions were usually deprived of food for 22 hours before a test session.

The experimenter worked from behind an opaque screen which was set out 15.2 cm from the dock area and extended down to the water line (see
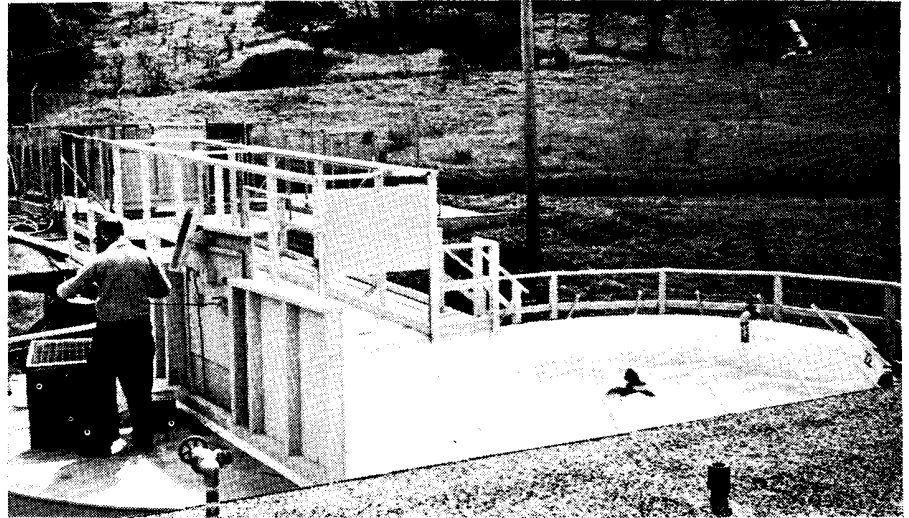

Fig. 1. A sea lion in the experimental tank waiting for a trial to begin. The experimenter is in the process of changing targets.

Fig. 1). Targets were presented simultaneously so that they projected below the opaque screen and were at least 38 cm below water level. At the beginning of a trial, a stimulus panel located behind the opaque screen was lowered to the water level. Attached to the side of the stimulus panel facing the experimenter were two rods, 114 cm in length and 0.64 cm in diameter. The targets were cut from 20-gauge sheet metal and were attached to the lower

Table 1. Description of training.

Training stimuli		No. of trials	Sea lion B		Sea lion C	
Problem sequence	Areas of paired targets (cm²)		No. of correct responses	p	No. of correct responses	p
Circles	289.8* and 6.35	20	4	<.05		
Circles	289.8 and 6.35*	50	45	<.01	47	<.01
Triangles	289.8 and 6.35*	50	48	<.01	50	<.01
Triangles	179.8 and 10.20*	50	49	<.01	47	<.01
Circles	179.8 and 10.20*	50	50	<.01	50	<.01

* Responses to these stimuli were reinforced.

Table 2. Values of standard and variable stimuli and percentage of responses to smaller stimulus (circles).

| Stimulus characteristics			Sea lion B			Sea lion C		
Stimuli	Area (cm²)	Ratio of variable to standard	No. of trials	Responses to smaller stimuli (%)	p	No. of trials	Responses to smaller stimuli (%)	p
−6	16.5	1 : 2.59	100	99	<.01	100	100	<.01
−5	26.6	1 : 1.61	120	98.3	<.01	200	91.5	<.01
−4	34.1	1 : 1.26	100	95	<.01	200	89	<.01
−3	38.0	1 : 1.13	200	82	<.01	200	83	<.01
−2	40.3	1 : 1.06	120	70.8	<.01	100	62	<.05
−1	41.7	1 : 1.03	20	50	>.05			
Standard	42.8	1 : 1						
1	43.9	1.03 : 1	20	60	>.05			
2	45.4	1.06 : 1	120	71.7	<.01	100	58	>.05
3	48.4	1.13 : 1	200	77.5	<.01	200	77	<.01
4	54.3	1.27 : 1	100	94	<.01	200	92	<.01
5	69.1	1.61 : 1	120	93.3	<.01	200	93.5	<.01
6	111.5	2.60 : 1	100	99	<.01	100	99	<.01
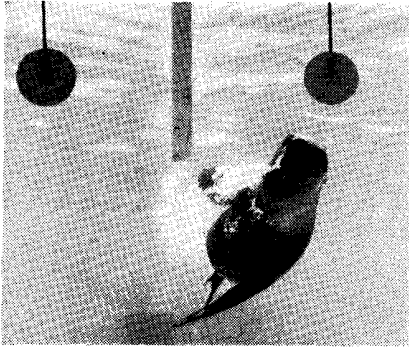
Fig. 2. A sea lion approaching the smaller of two targets. The size ratio of the larger to smaller target is 1.13:1.00.

portion of each rod by means of set screws. Deflection of either rod activated a microswitch and produced a light signal behind the stimulus panel. A perpendicular divider of 3.8-cm pine projected 45 cm downward from the water level and 45.7 cm outward from the opaque screen, thus lying between the targets and preventing the animals from moving laterally from one target to the other. The distance between the centers of any two targets was 57.2 cm (Fig. 2).

Prior to formal testing both animals were trained to push with their noses against a single square-shaped target (42.8 cm² in area). The position of the target was randomly determined within blocks of ten trials. Preliminary training was discontinued when subjects immediately began approaching the submerged stimulus display from a starting position 5 to 6 m in front of the testing platform or dock. Between trials the subjects remained near the starting position until they were signaled to approach by the sound of the stimulus display being lowered into the water. During formal testing the sea lion's task was to push one of two targets (differing in size) in order to obtain a small piece of herring (*Clupea pallasi*) weighing approximately 5 g. The stimulus display was immediately withdrawn following either a correct or an incorrect response. The position of the target was an irrelevant cue throughout all phases of this investigation.

After preliminary training on a single target, subjects were tested with two pairs of black circular targets and two pairs of black triangular targets. A test session consisted of 50 trials and learning criterion was designated as 90 percent correct responses at a given

test session. The sequence of testing, target magnitudes, and results are shown in Table 1.

Although we originally planned to train sea lion B to respond to the large target and sea lion C to the small target, on the initial discrimination task both animals showed a strong preference for the small target. This preference resulted in virtually errorless performance by sea lion C and persistent incorrect responding and subsequent non-test-oriented or emotional behavior by sea lion B. For this reason, after the first 20 trials, sea lion B also received fish rewards for responding to the smaller target of each pair. As Table 1 shows, on the basis of this size preference, the performance of both animals was virtually errorless despite changes in the relative size and form of the targets. In general, the preference for a very small target as compared to a very large target is consistent with the notion that, in novel situations, increasing excitation or large amounts of stimulation lead to avoidance behavior, and low or decreasing degrees of excitation will elicit approach responses (6).

In obtaining the size threshold, we took advantage of this preference, which, as far as our experimental treatment was concerned, may be considered an "untrained" discrimination and therefore was probably influenced by fewer irrelevant variables than are most trained discriminations. We sustained the indicator response (pushing the target) by reinforcement procedures throughout testing.

Differential size-thresholds were obtained by the psychophysical method of constant stimuli. The animals were always required to respond in accordance with their previous training. Each variable stimulus was paired with the standard stimulus for ten consecutive trials and, generally, four pairs were presented at each test session for a total of 40 trials per session. Random sequences of paired presentations were given from session to session.

In the first experiment dealing with size threshold, black circular disks were used as the stimuli. The results of this experiment are presented in Table 2, which shows that, as the magnitude of the size-difference ratios decreases, there is a corresponding decrease in correct responses. The table also reveals that both animals were capable of discriminating a size-difference ratio as small as 1.06:1.

To appreciate the fineness of this discrimination, we compared our results with sea lions underwater to those results obtained by Klüver (7) with two Java monkeys. The monkeys were given a great number of size discrimination problems with two rectangles. On one problem, with one of the smallest difference ratios—on the order of 1.06:1—one animal got 70 percent correct in 420 trials and the other got 61 percent correct in 365 trials. Surprisingly, the scores were almost identical to the two sea lions at the same difference ratio. It should be noted that Klüver's monkeys were generally at a fixed distance of approximately 1.23 m from the stimuli, whereas the sea lions started their approach at approximately 5 to 6 m away and rarely got closer than 1 m before making a choice.

A second experiment dealing with size threshold was conducted with black triangular targets. In this experiment we forced the animal to make a decision at least 1.23 m prior to its giving the indicator response. This was accomplished by replacing the previously used perpendicular divider with one which projected 1.23 m outward from between the stimulus targets and all the way down to the floor of the tank. The data of this experiment were practically identical to those obtained with circular targets.

Our results suggest that under natural illumination (sunlight) the ability of the California sea lion to discriminate objects underwater on the basis of size may be as good as the ability of some monkeys to discriminate objects in air on the basis of size. Indeed, these behavioral data confirm the anatomical evidence (4) suggesting that pinnipeds have compensated for the loss of the refractive power of the cornea underwater by having a large spherical lens which produces enough accommodation to form a reasonably well-defined image on the retina.

Throughout these experiments (8) underwater monitoring revealed no sounds suggestive of pulses or clicks used for the purpose of echo-location. On infrequent occasions, we did obtain bubble sounds and underwater barks.

Upon completion of the experiments, sea lion B was presented with a size-discrimination task on moonless nights and did emit trains of pulses while swimming toward the targets. One tentative hypothesis concerning the click emission of sea lions seems to emerge from these investigations. Namely,

2

that sea lions emit clicks primarily when visual cues are scarce or unavailable, but depend principally upon their visual sense for purposes of detecting and discriminating underwater objects.

RONALD J. SCHUSTERMAN
WINTHROP N. KELLOGG
CHARLES E. RICE

*Stanford Research Institute
Menlo Park, California 94025*

References and Notes

1. W. E. Evans and R. Haugen, *Bull. S. Calif. Acad. Sci.* **62**, 165 (1963); T. C. Poulter, *Science* **139**, 753 (1963); W. E. Schevill, W. A. Watkins, C. Ray, *ibid.* **141**, 50 (1963).
2. W. N. Kellogg, *Porpoises and Sonar* (Univ. of Chicago Press, Chicago, 1961).
3. T. C. Poulter, *Inst. Elec. Electron. Eng. Trans.* **10**, 109 (1963).
4. G. Walls, *The Vertebrate Eye* (Cranbrook Inst. Science. Bloomfield Hills, Mich., 1942), p. 446.
5. The following equipment was used for monitoring and recording underwater sounds. Hydrophones: (i) Channel Industries 275 (20 cy/sec to 150 kc); (ii) Fishphone (750 cy/sec to 6.5 kc). Recorders: (i) Vega at 60 inches per second (1.5 m/sec) (150 cy/sec to 150 kc); (ii) Ampex 601 at 7.5' inches per second (20 cm/sec) (30 cy/sec to 18 kc). Preamplifier: Burr-Brown Model 100. Amplifier and speaker: Webster-Chicago 66-1A.
6. D. Bindra, *Motivation: A Systematic Reinterpretation* (Ronald, New York, 1959); E. W. Menzel, *J. Comp. Physiol. Psychol.* **55**, 1044 (1962).
7. H. Klüver, *Behavior Mechanisms in Monkeys* (Univ. of Chicago Press. Chicago, 1933).
8. Supported by NSF grant GB-1437. We gratefully acknowledge the assistance of Garth Rader who helped in testing the animals.

7 December 1964