

UNDERWATER CLICK VOCALIZATIONS BY A CALIFORNIA SEA LION: EFFECTS OF VISIBILITY¹

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A 2 yr. old captive sea lion (*Zalophus californianus*) presented with a discrimination task permitting little visibility of the targets gradually increased the frequency with which it made a series of underwater clicks. Further tests revealed that the amount of clicking elicited was inversely related to the degree of visibility and that the animal was incapable of discriminating between inanimate targets of different size and sound-reflecting characteristics on the basis of active sonar alone.

Although a number of investigators have found that captive sea lions make clicking sounds² while presumably searching for underwater objects (Evans & Haugen, 1963; Poulter, 1963a; Schevill, Watkins & Ray, 1963), they are not in agreement as to whether these vocalizations actually are used for purposes of echo-location under water. Whereas Poulter (1963b) claims that underwater clicks by the sea lion are ideally suited for echo-detection behavior, Schevill et al. are not as confident, especially in terms of a long-range detection system. In contrast to Poulter's experiments, which were conducted in the dark, Schevill et al. tested their animals under daylight conditions and although Evans & Haugen attempted to eliminate visual cues in an early experiment, they admit that they were not very successful in this endeavor.

Recently, behavioral experiments (Schusterman, Kellogg & Rice, 1965) have confirmed the anatomical and physiological evidence suggesting that sea lions have rather good underwater visual acuity. In that report, it was suggested that sea lions may produce clicks primarily under conditions of poor visibility, but depend principally upon visual cues, when available, for purposes of perceiving underwater objects. That visibility plays a role in the click production of other mammals suspected of having a biological sonar system is suggested by Novick's evidence (as cited by Griffin, 1958) that some fruit-eating bats, of the genus *Rousettus*, orient themselves visually when light is present, but depend on easily audible clicks in the absence of visual cues.

This report describes a series of exploratory experiments designed to obtain information relevant to the following questions: (a) Does the

¹ This research was supported by NSF Grant GB-1437 and was presented at the 1965 meetings of the Eastern Psychological Association, Atlantic City, N J.

² A click has been defined as a discrete sound pulse of short duration (see Broughton, 1964).

California sea lion make clicking sounds primarily when it is seeking information relevant to feeding? (b) Does the amount of clicking vary systematically as a function of underwater visibility? (c) Does the California sea lion possess an active sonar system which enables it to discriminate targets of different sizes and different sound-reflecting characteristics without benefit of other sensory cues?

GENERAL METHOD

A wild-born female California sea lion (*Zalophus californianus*) served as the S in the experimental series which began in June, 1964, and terminated in January, 1965. The animal was approximately 2 yrs. old and had been in captivity for 4 mos. at the start of this study. All testing was conducted in an outdoor tank constructed of redwood, the inside walls and bottom of which were painted white (see Fig. 1).

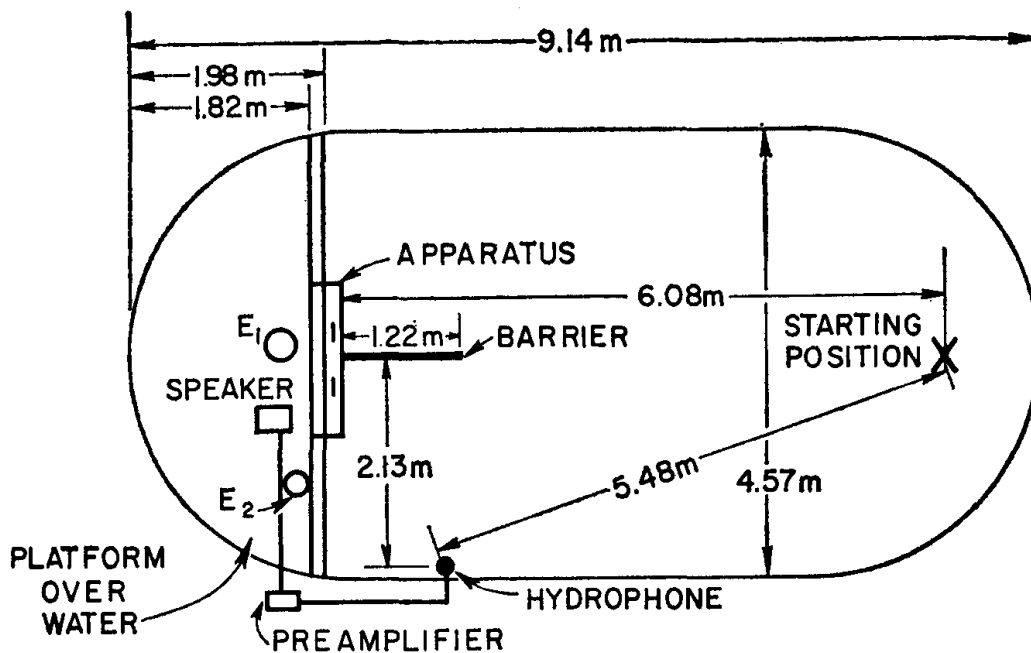


Fig. 1. Plan of the experimental tank, showing location of test apparatus, recording equipment and starting position of the sea lion.

The testing conditions and apparatus have been previously described in detail (Schusterman, Kellogg & Rice, 1965). The animal had been trained to remain at a starting position 5.48 to 6.08 m in front of a testing platform until it was signaled to approach by the sound of the stimulus display being lowered into the water. The sea lion's task was to strike one of two target stimuli in order to obtain a small piece of herring. Depending on the experiment, a perpendicular divider made of chicken wire projected either 1.2 m or .46 m outward between the targets and all the way down to the floor of the tank. The targets were suspended below the water surface by two rods 114 cm in length and .64 cm in diameter. The distance from the center of a target to the

water surface was .43 m. Underwater sounds were monitored throughout the entire series of experiments by means of a hydrophone and speaker system.

The following equipment was used: Hydrophones; (a) Channel Industries 275 (20 cps–150 kc), (b) Fishphone (750 cps–6.5 kc). Recorders; (a) Vega at 60 ips (1.5m/sec) (150 cps–150 kc), (b) Ampex 601 at 7.5 ips (20 cm/sec) (30 cps–18kc). Preamplifier; Burr-Brown Model 100. Amplifier and speaker; Webster-Chicago 66-1A.

Two *Es* were usually present during the course of these studies. One *E* presented the stimulus display and reinforced appropriate responses, while the other observed the animal from the testing platform, recording correct responses, presence or absence of a click series during and between stimulus presentations or trials, reaction time, and time between trials.

EXPERIMENT 1

Method

The first study began after it was determined that the animal occasionally produced clicks when approaching targets on moonless nights. The experiment took place at night and was composed of three phases. In the first phase, the sea lion was tested with black circular targets made of 20-gauge steel under light³ and then dark conditions; in the second phase, .64 cm thick transparent plexiglass targets were used and all trials were given in the dark; the third phase repeated the first phase except that the dark condition came first. Phases 1 and 3 were run on the first and last nights of the experiments and Phase 2 was run for 100 or 125 trials on each of the four intervening nights. During all three phases *S* was required to respond in accordance with its previous training (Schusterman et al., 1965), i.e., to the smaller of two targets (456.7 cm² vs. 25.9 cm²). The general procedure for testing in the dark was to lower the targets in the water as soon as the lights were turned off and then instantly to turn them back on again when the animal struck the target. This procedure served a dual function. It enabled the *E* to verify the starting position of the animal and served to decrease *S*'s visual sensitivity during a trial, since *S* was never permitted to become fully dark-adapted.

Results and Discussion

The results depicted in Fig. 2 clearly show that although the sea lion gradually increased the frequency with which it produced a series of clicks during target presentation to a point where clicking occurred during practically every trial, the production of clicks remained relatively infrequent between trials. This occurred despite the fact that duration of test trials (2 to 5 seconds) permitted emission of only a single series of clicks, whereas time between trials (25 to 50 seconds) allowed for emission of several distinctly separate trains of clicks. Between trials

³ Five overhead 150 w lamps were used to illuminate the testing tank.

two or more series of clicks were scored only when separated by at least a five-second silent period. Typically the clicks between trials occurred when the animal was swimming back to its starting position.

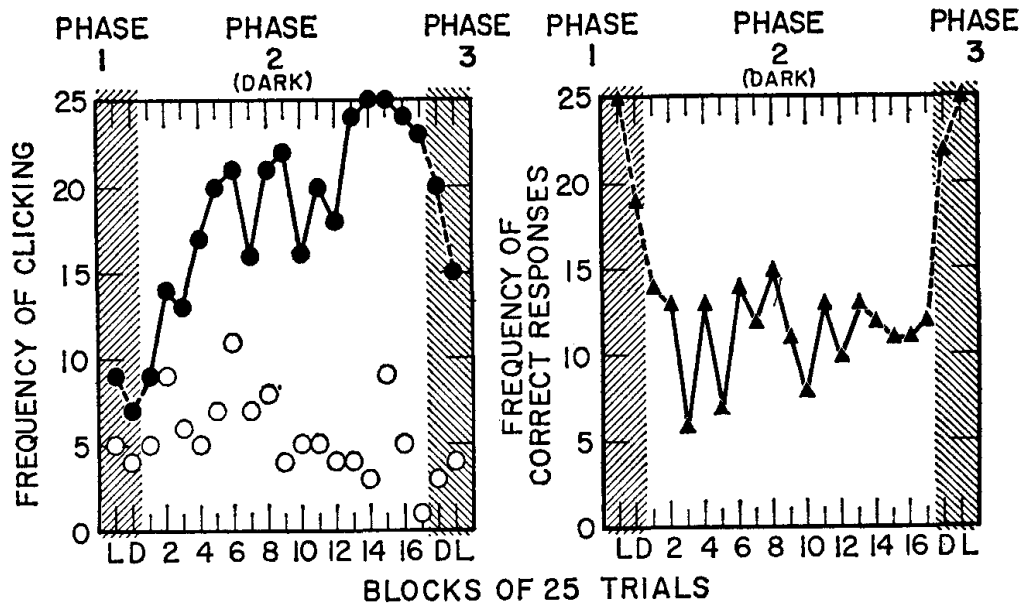


Fig. 2. Frequency of clicking and correct responses as a function of trials and visibility. Symbols L and D refer to light and dark conditions. Solid circles refer to clicking during a trial; open circles refer to clicking between trials.

A sonogram of the signals produced during one of the trials is shown in Fig. 3. In contrast to those signals of the California sea lion reported by Schevill et al. (1963) and Evans and Haugen (1963) in which the signals had little or no energy at 6 to 8 kc, our S's signals show a great deal of energy at 14 to 16 kc.

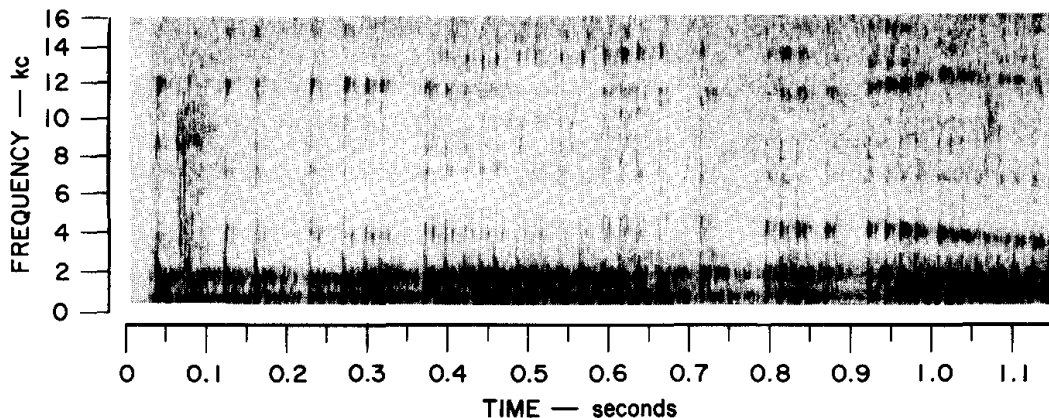


Fig. 3. Sonogram of underwater clicks by a California sea lion during a test trial.

In terms of correct responses the data indicate that although the animal was utilizing visual cues when confronted with the black target discrimination, such was not the case when it was presented with clear plexiglass targets.

The question as to whether clicking is evoked solely by stimuli signaling food presentation or by such sign stimuli which are difficult to see was not clearly answered due to the nature of the experimental design. However, since clicking did occur most frequently when the animal was swimming toward the stimulus display under conditions affording little or no visual information, a reasonable hypothesis is that clicking by the sea lion functions as an information-seeking response and is one aspect of an orientation reflex (Berlyne, 1960). Effects of food reinforcement on clicking should have been negligible since correct responses or reinforced trials tended to be inversely related with clicking trials. This inverse relationship between clicking and food reinforcement suggests the possibility that clicking may also have been a function of feeding frustration in this experiment.

EXPERIMENT 2

In order to test some of the alternative hypotheses regarding the factors affecting the production of clicks and further to test the sea lion's sonar capabilities, a second experiment was conducted which afforded much greater control over the presence of underwater visual cues than heretofore had been the case.

Method

In all of the following experiments a harmless vegetable dye called Cloud was poured into the water and testing was conducted during daylight hours. Cloud is a product of the Warner-Jenkinson Mfg. Co. of Los Angeles; it is made from turpines of orange oil and is put into soft drinks to give them a cloudy appearance.

The stimulus presentation was always a black target of 20-gauge steel (736 cm² in area) paired with the rod which normally holds a target. Prior to the initiation of this experiment the animal was first retrained at night to respond to the target while the lights were on, and it produced only three bursts of clicks during 50 trials. It was then tested in the dark and at the end of 175 trials was clicking on 92 per cent of the trials. Immediately following the above-described training, the second experiment was carried out on three successive days.

Results and Discussion

In addition to presenting the results, Fig. 4 shows the sequence of test phases and the visibility conditions, i.e., the maximum distance at which a skin diver could perceive the target. The most salient features of the curves depicted in the figure are: (a) the frequent clicks manifested during the initial clear water condition followed by a rapid decline, (b) the inverse relationship between frequency of click production and visibility, (c) the ability of the sea lion to discriminate between the target and the rod *only* when it was afforded the opportunity to visually inspect the stimuli, i.e., when it was permitted to make a decision at a point where visual cues were still available, and (d) the infrequent occurrence of clicking between trials in this experiment relative to the first experiment.

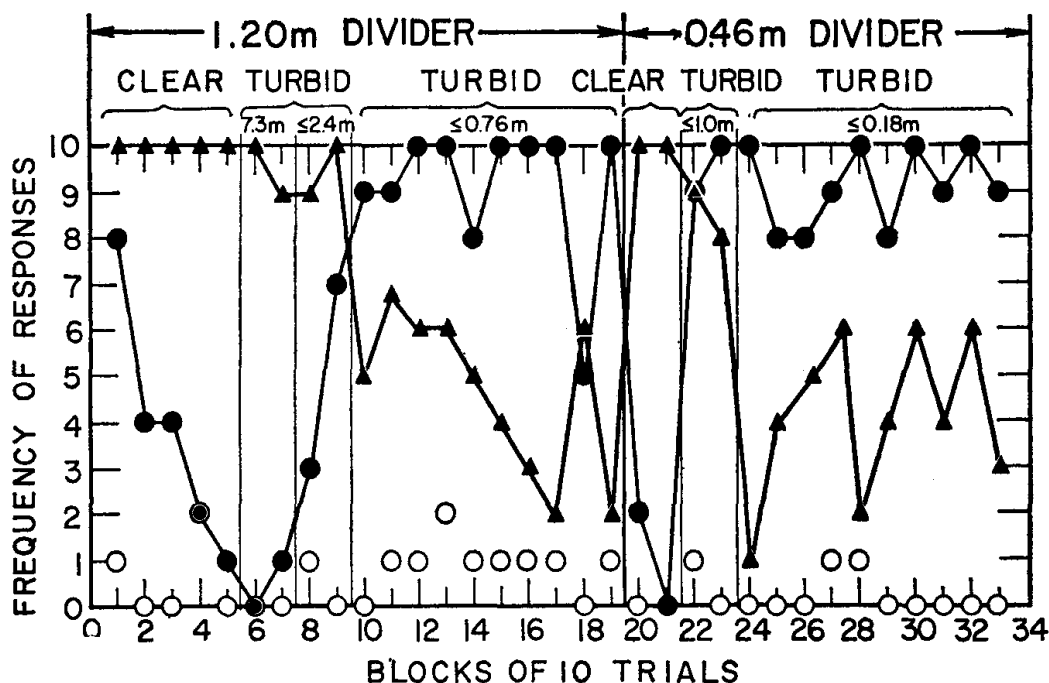


Fig. 4. Frequency of clicking and correct responses as a function of trials and underwater visibility. Solid circles refer to clicking during a trial; open circles refer to clicking between trials; solid triangles refer to correct responses. Divider measurements refer to the distance that a barrier extended outward between the targets. Turbid measurements refer to maximum distance skin diver could see a target.

These results support the hypothesis that short pulsed sounds or clicks are likely to be produced by a California sea lion when it is aroused and seeking information relevant to feeding and that the frequency with which a series of clicks is elicited is a decreasing function of the degree of visibility. Furthermore, the data indicate that clicking by the sea lion tends to habituate rapidly in clear water and that the initially frequent occurrence of clicking in clear water is primarily a function of the high rate of clicking which was produced in previously turbid water. In all these respects, the underwater vocalizations by the California sea lion appear to conform to many of the principles that have been found to govern the orientation reflex (Berlyne, 1960). Indeed, vocalization has been reported to be one component of the orienting reflex in both dogs (Robinson & Gantt, 1944) and chickens (Andrew, 1964).

EXPERIMENTS 3 AND 4

At this point a series of exploratory studies were made to determine the most suitable testing conditions and procedures for eliminating the use of visual cues by the sea lion while permitting the *E* to make detailed observations of the animal as it swam toward the target area. Throughout these explorations, it was found that the animal would persist in developing strategies which enabled it to utilize visual cues in order to discriminate between the two targets or between a rod and a target.

Method

In order to correct for these difficulties during the next two experiments, which were designed specifically to test the California sea lion's sonar capabilities, the 1.2 m perpendicular divider or barrier was used under turbid water conditions affording a maximum visibility of from 0.56 m to 0.69 m. An incorrect response was scored when the animal's nose was .20 m past the side of the barrier on which the incorrect target was located. In the first of these two experiments two black circular discs made of 20-gauge steel (736.1 cm² and 16.1 cm² in area) were presented to the animal, and responses to the larger target were always reinforced. Under these conditions the animal received 500 trials over a period of three days.

In the second experiment the animal was presented with an air-plexiglass target paired with the rod and responses to the former target were always reinforced. The air-plexiglass target consisted of two circular discs of .64 cm clear plexiglass sandwiched together in such a manner as to leave a .64 cm air space between the two pieces of plexiglass. The surface area of the air space was 736.1 cm². Such a target forms an excellent impedance mis-match under water and should offer a good sound-reflecting surface (Parvulescu, 1964). Under these conditions the animal received over 2000 trials for a period of 10 days.

Results

Results from both experiments showed that although the animal produced a series of clicks virtually during each stimulus presentation, performance in terms of correct responses remained near a chance level throughout the course of testing.

During the course of both the exploratory studies and these two experiments, observations indicated that the animal often would make a series of clicks soon after diving underwater at a distance of 4 to 5 m from the stimulus display. Then, the animal would swim to the right of the barrier, slow its swimming speed, duck its head approximately .15 m past the barrier without committing itself, continue clicking for a moment, terminate clicking, and then either continue forward to the target on the right or swim laterally to its left and then forward, past the edge of the barrier toward the target on the left.

CONCLUSIONS

Although these experiments have demonstrated that visibility plays an important role in the production of underwater clicks by a California sea lion, they have also raised some doubts concerning the capabilities of this animal to discriminate between inanimate targets of different size and sound-reflecting characteristics on the basis of sonar alone. This is especially true since there was no clicking elicited from a second sea lion tested in turbid water, although operant conditioning techniques eventually proved to be successful (Schusterman & Feinstein, 1965). This is not to say that some of these animals do not use their sonar-like

clicks for purposes of discriminating between food objects and navigating in their natural environment. Such factors as the interfering reverberations of the test tank, the limited kinds of targets and test situations thus far employed, the length of captivity and the immaturity of the animals might possibly place a severe limitation on the sea lion's sonar capabilities. However, in spite of our present meager knowledge about the biological sonar system of marine mammals, it would appear that under laboratory conditions the use of active sonar is more prevalent in the porpoise, *Tursiops truncatus* (Kellogg, 1961; Norris, Prescott, Asa-Dorian & Perkins, 1961), than in the sea lion, *Zalophus californianus*. The present results, in conjunction with some recent unpublished data by Roger Gentry (of our laboratory) on the localization of underwater sounds, suggest that *Zalophus* may depend more on vision and passive sonar (hearing) than on active sonar for the detection and discrimination of underwater objects.

It is important to note that a communication received by the author subsequent to the termination of the present series of experiments revealed that the present results are in close agreement with some, as yet, unpublished observations by William E. Evans (personal communication, 1965). Evans reports that of five California sea lions with which he has worked (two of which have been trained to work untethered on a retrieval task in the open ocean), two have produced underwater clicking sounds and three have not. Furthermore, he reports that the two animals produced clicks far more frequently in turbid water and at night than in clear water during the day.

REFERENCES

- ANDREW, R. J. 1964. Vocalization in chicks and the concept of "stimulus contrast." *Animal Behav.*, 7, 64-76.
- BERLYNE, D. E. 1960. *Conflict, arousal, and curiosity*. New York: McGraw-Hill.
- BROUGHTON, W. B. 1964. Method in bio-acoustic terminology. In R. G. Busnel (Ed.) *Acoustic behaviour of animals*. Amsterdam: Elsevier.
- EVANS, W. E. & HAUGEN, R. 1963. An experimental study of the echo-location ability of a California sea lion, *Zalophus californianus* (Lesson). *Bull. S. Calif. Acad. Sci.*, 62, 165-175.
- GRIFFIN, D. R. 1958. *Listening in the dark*. New Haven: Yale Univ. Press.
- KELLOGG, W. N. 1961. *Porpoises and sonar*. Chicago: Univ. Chicago Press.
- NORRIS, K. S., PRESCOTT, J. H., ASA-DORIAN, P. V., & PERKINS, P. 1961. An experimental demonstration of echo-location behavior in the porpoise, *Tursiops truncatus*. *Biol. Bull.*, 120, 163-176.
- PARVULESCU, A. 1964. Problems of propagation and processing. In W. N. Tavolga (Ed.) *Marine bio-acoustics*. New York: Pergamon.
- POULTER, T. C. 1963. Sonar signals of the sea lion. *Science*, 139, 753-755. (a)
- POULTER, T. C. 1963. The sonar of the sea lion. *Inst. Elec. Electron. Eng. Trans.*, 10, 109-111. (b)
- ROBINSON, J. & GANTT, W. H. 1947. The orienting reflex (questioning reaction): cardiac, respiratory, salivary and motor components. *Johns-Hopkins Hospital Bull.*, 80, 321-353.
- SCHEVILL, W. E., WATKINS, W. A. & RAY, C. 1963. Underwater sounds of pinnipeds. *Science*, 141, 50-53.
- SCHUSTERMAN, R. J., KELLOGG, W. N. & RICE, C. E. 1965. Underwater visual discrimination by the California sea lion. *Science*, 147, 1594-1596.
- SCHUSTERMAN, R. J. & FEINSTEIN, S. H. 1965. Shaping and discriminative control of underwater click vocalizations in a California sea lion. *Science*, 150, 1743-1744.