

California sea lion underwater auditory detection and variation of reinforcement schedules*

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A sea lion (*Zalophus californianus*) was trained to report the presence of a pure tone under water in a yes-no psychophysical procedure. The payoff matrix was varied by altering the probability of fish reinforcement [$P(S^R)$] contingent on two classes of response—hits and correct rejections (CR). The $P(S^R|\text{Hit})$ and the $P(S^R|\text{CR})$ were 1.00, 0.75, 0.50, and 0.25. In baseline, both $P(S^R|\text{Hit})$ and the $P(S^R|\text{CR})$ were = 1.00. In the asymmetrical payoff matrices $P(S^R)$ was held constant at unity for one response and varied over three values for the other response. Thus, seven different payoff matrices were used. The sea lion showed rapid acquisition of a stable response bias independent of its ability to detect the underwater auditory signal. These results demonstrate that varying reinforcement probability is functionally equivalent to varying amount of reinforcement in the control of response bias in underwater signal detection by sea lions [see R. J. Schusterman, B. Barrett, and P. Moore, *J. Acoust. Soc. Am.* 57, 1526–1532 (1975)].

Subject Classification: [43]80.50, [43]80.60.

INTRODUCTION

Unlike human subjects, nonhuman animals cannot be verbally instructed regarding the strictness or laxity of decision criterion in a psychophysical task. However, their criterion or bias can be determined by values and costs associated with the consequences of their responses.^{1,2} Although biasing factors frequently influence an animal's performance in yes-no psychophysical tasks, signal detectability analysis may enable one to differentiate between variables affecting the discriminative ability or sensitivity of an animal and variables which influence how that animal responds in the presence of different signals. Several recent studies with marine mammals have shown that in underwater auditory tasks, variation in such nonsensory variables as signal probability³ and symmetry of the payoff matrix⁴ resulted in systematic changes in response bias or response criterion of sea lions and a porpoise without altering their ability to discriminate between signal (sn) and noise (n). In the payoff matrix experiment the matrix was made asymmetrical by altering the amount of reinforcement (number of fish) contingent on the two different classes of correct responses. In terms of the ratio of hits to correct rejections the matrix was varied over three values 1:1, 4:1, and 1:4.

In research with pigeons (with rate of response as a measure of "choice") it has been shown that when multiple or concurrent schedules of reinforcement are used, amount of reinforcement is functionally equivalent to probability of reinforcement.^{5–10} If amount of reinforcement and probability of reinforcement are functionally equivalent, then in an auditory detection task making the payoff matrix asymmetrical (see Table I) by varying the probability of fish reinforcement [$P(S^R)$] consequent on the two classes of correct responses of marine mammals would be as effective in altering their response bias as was the previous method of employing an asymmetrical payoff matrix by varying the amount of reinforcement. The present experiment attempted to test this hypothesis with a California sea lion (*Zalophus californianus*) by holding stimulus parameters constant while manipulating the probability

of fish reinforcement for hits [$P(S^R|\text{Hit})$] and the probability of fish reinforcement for correct rejections [$P(S^R|\text{CR})$] over a range of seven values (see Table I).

I. METHODS

The experimental subject (Sam) was a nine-to-ten-year old male *Zalophus* who had just previously served as a subject in an experiment in which the strength of an underwater auditory signal and the payoff matrix (in terms of amount of reinforcement) were varied concurrently.⁴ The experimental situation was a 3.5 × 11.1 × 1.2-m concrete pool which had a testing platform at one end with a vertical opaque screen preventing the sea lion from viewing the experimenter. A detailed description of the structural as well as the acoustical characteristics of the pool in which the experiment was conducted may be found in Ref. 4. Moreover, signal and ambient noise measurements of the sound field in which the sea lion maintained its head in a fixed position may also be found in this article. A lead zirconate titanate transducer (F50) was used to emit a 16-kHz tone under water at a sound pressure level of -11 dB ($\approx 1 \mu\text{bar}$) at the sea lion's head. Measurements of the standing wave ratio in the testing pool with a 16-kHz tone of 0.5-sec duration was about 13 dB. There was evidence of multipath interference causing resultant signal-level fluctuations in the sound field. Primary interfering paths were *direct* and *surface* reflected signals and hydrophone (H-56) measurement of positions were in general accord with expected distance variation for this primarily two-path signal interference at 16 kHz, i. e., approximately 5.1 cm.

TABLE I. Payoff matrix.

Response and $P(S^R)$	Stimulus configurations	
	$sn + n$	n
Vocalization (yes) $P(S^R)$	Hits 0.25, 0.50, or 1.00	False alarms 0.00
Silence (no) $P(S^R)$	Misses 0.00	Correct rejections 0.25, 0.50, or 1.00

TABLE II. Sequence of reinforcement schedules.

Condition	$P(S^R \text{Hit})$	$P(S^R \text{CR})$
1 ^a	1.00	1.00
2	1.00	0.25
3 ^a	1.00	1.00
4	0.25	1.00
5 ^a	1.00	1.00
6	0.50	1.00
7 ^a	1.00	1.00
8	1.00	0.50
9 ^a	1.00	1.00
10	1.00	0.75
11 ^a	1.00	1.00
12	0.75	1.00
13 ^a	1.00	1.00

^aRefers to baseline condition.

The sea lion's task was to detect the presence of an acoustic signal (16-kHz tone) by vocalizing, i. e., emitting a burst of underwater clicks (yes report) with 1.5 sec of signal presentation and to report its absence by remaining silent (no report) for 3.5 sec following the beginning of a trial. After the sea lion placed its head in a fixed position a trial began by presenting a light for 2.5 sec. On one-half of the trails the acoustic signal was presented during the final 0.5 sec of the 2.5-sec light duration. Table I shows the 2x2 payoff matrix that was used in the present experiment and includes the two types of correct responses (hits and correct rejections) with their associated reinforcement contingencies and the two types of errors (misses and false alarms). Positive reinforcement was delivered to the sea lion at the headstand by the experimenter throwing him a piece of herring weighing approximately 13 g. Errors were neither positively reinforced nor explicitly punished. The intertrial interval was 10 sec. Under all conditions of the experiment the sea lion was maintained on approximately 15-20 lb. of fish/day; including the amount of fish earned during experimental sessions.

The signal intensity was chosen on the basis of previous experimentation.^{4,11} A daily experimental session consisted of 200 test trials (100 in the morning and 100 in the afternoon) excluding at least a 20-trial warm-up period prior to both the morning and afternoon sessions. The warm-up signals were 4-8 dB stronger than the signal used in the experimental sessions and reinforcement probabilities for the actual experimental test sessions also prevailed during the warm-up period.

Reinforcement probabilities less than unity were constructed such that the likelihood of successive reinforcement or nonreinforcement for correct responses never exceeded six.

Table II presents the sequence of reinforcement schedules for each of the seven different matrices. The symmetrical payoff matrix in which the $P(S^R | \text{Hit})$ and the $P(S^R | \text{CR})$ equalled unity was used as a constant baseline which was returned to for six daily sessions (with

one exception) following six sessions of an asymmetrical payoff matrix. During the fifth condition (see Table II) baseline was extended an additional four sessions because the sea lion's performance was extremely inconsistent due, in all likelihood, to a decrease in food motivation (see Ref. 12 for a discussion of seasonal weight fluctuations and feeding of adult male *Zalophus*). Although at least six experimental sessions were conducted for each of the six asymmetrical matrices and for the baseline conditions, the first session following a change in reinforcement probabilities was excluded from the analysis of the results.

II. RESULTS AND DISCUSSION

Figures 1 and 2 present the conventional signal detection plots² with hits ($y|sn$) on the ordinate and false alarms ($y|n$) on the abscissa. In Fig. 1 the baseline data points were based on five daily experimental sessions or 1000 trials, whereas each of the data points generated by asymmetry in the payoff matrix was based on one daily experimental session or 200 trials. Despite showing a good deal of variability from session to session (probably due to the signal-level fluctuations in the sound field) the data points do exhibit a marked degree of predictability based upon the differential $P(S^R)$ for hits and correct rejections. The data points sweep out from the lower left to the upper right along an iso-sensitivity contour. There is no overlap between the open data points which represent performances based on reinforcement schedules favoring hits, and solid data points which represent performances generated by reinforcement schedules favoring correct rejections. The baseline data points (X 's) fall predictably between the open and solid data points. As expected, the open cir-

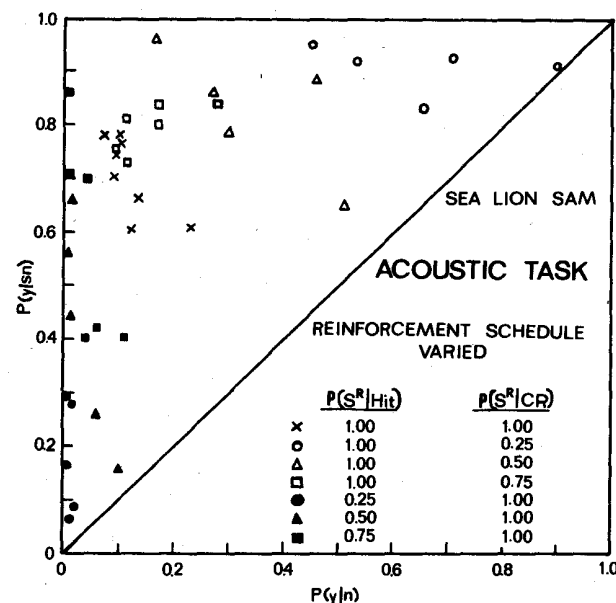


FIG. 1. Conditional response probabilities of a California sea lion as a function of the probability of reinforcement for hits and correct rejections. The intensity of the 16-kHz tone was -11 dB re 1 μbar under water. The X's are based on at least 1000 trials. All other data points are based on 200 trials.

cles are found in the upper right-hand corner and the solid circles are found in the lower left-hand corner. In general, the other data points fall predictably along an isosensitivity contour. Figure 2 shows this relationship more clearly since the results obtained by varying the payoff matrix in terms of reinforcement probability are pooled and lines connect each of the points.

The best way to determine whether sensitivity to an underwater auditory signal was affected by systematic changes in response bias is to plot the data points shown in Fig. 2 on double-probability paper with response probabilities transformed into Z units. If the sea lion's ability to discriminate between sn and n was independent of response bias then the data points of Fig. 2, when plotted on two axes marked off in normal linear deviates, should yield a straight line with a slope of 1.0. Figure 3 shows that the function is close to linearity and that the slope does approximate 1.0. The line drawn through the data points was designed to go through the baseline data point and be parallel with the major or positive diagonal (chance line).

The results of this experiment clearly support the notion that in an auditory detection task with a sea lion systematic changes of response bias or criterion can be brought about just as effectively by varying outcomes of the matrix in terms of reinforcement schedules as by varying outcomes of the matrix in terms of amount of reinforcement (see Ref. 4). These results have important implications regarding the conditions under which amount and probability of reinforcement are functionally equivalent.

Whether the matrix is made asymmetrical by altering the probability of reinforcement or by altering the amount of reinforcement, the auditory sensitivity of

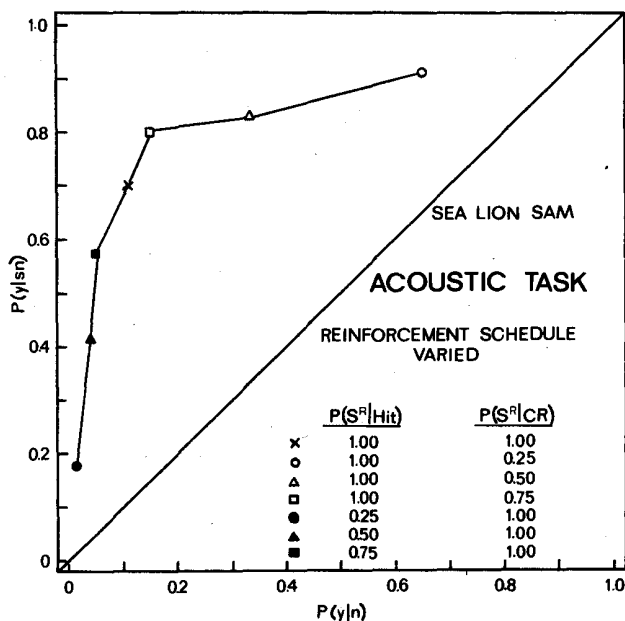


FIG. 2. An isosensitivity or relative operating characteristic curve (ROC) for a California sea lion.

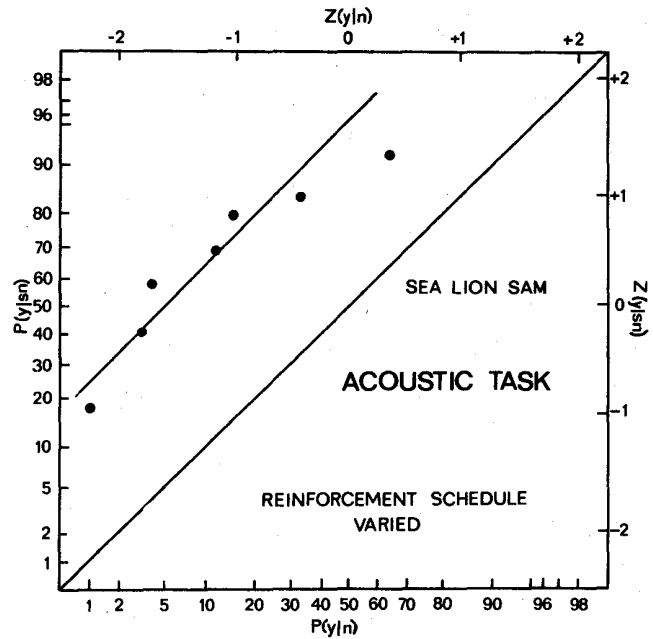


FIG. 3. The same ROC curve plotted on two axes marked off on linear normal deviates.

Zalophus appears to be relatively unaffected by its response bias. The extreme bias conditions of the present experiment did result in at least one data point deviating from the theoretical isosensitivity function and falling close to the major diagonal or chance line (see Fig. 1). Similar results have been found in extreme bias conditions for other species (see, e.g., Refs. 13 and 14).

It has been previously pointed out that many investigators doing auditory psychophysics with nonhuman animals (particularly marine mammals) have inadvertently constructed dependencies and contingencies of reinforcement resulting in their animal subjects biasing their response and adopting a "strict" or "medium strict" criterion.¹⁵ Such was the case in the present experiment with California sea lion Sam. If in Fig. 1 or Fig. 2 a negative or minor diagonal was drawn from the upper left-hand corner to the major diagonal, such a line would represent equal bias or a "medium" response criterion. All those data points to the lower left of this equal-bias line would represent biases away from vocalization or the adoption of a relatively strict criterion while those data points to the upper right would represent biases toward vocalization or the adoption of a relatively lax criterion. Note that in Fig. 1, the data points that are clumped around the imaginary equal bias line are the open squares and that the X's are located to the left. Thus, the baseline or symmetrical payoff condition continually resulted in the sea lion adopting a medium strict criterion, whereas equal bias or the adoption of a medium criterion occurred under the asymmetrical payoff condition where the $P(S^R | \text{Hit})$ was = 1.00 and the $P(S^R | \text{CR})$ was = 0.75. Similar results have been found with the same sea lion when amount of reinforcement was varied.⁴

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- ¹J. A. Nevin, "On Differential Stimulation and Differential Reinforcement," in *Animal Psychophysics: The Design and Conduct of Sensory Experiments*, edited by W. C. Stebbins (Appleton-Century-Crofts, New York, 1970), pp. 401-424.
- ²J. A. Swets, "The relative operating characteristic in psychology," *Science* 182, 990-1000 (1973).
- ³R. J. Schusterman and B. W. Johnson, "Signal probability and response bias in California sea lions," *Psychol. Rec.* 25, 39-45 (1975).
- ⁴R. J. Schusterman, B. Barrett, and P. Moore, "Detection of underwater signals by a California sea lion and bottlenose porpoise: variation in the payoff matrix," *J. Acoust. Soc. Am.* 57, 1526-1632 (1975).
- ⁵A. C. Catania, "Concurrent performances: reinforcement interaction and response independence," *J. Exp. Anal. Behav.* 6, 253-263 (1963).
- ⁶A. C. Catania, "Concurrent performances: A baseline for the study of reinforcement magnitude," *J. Exp. Anal. Behav.* 6, 299-300 (1963).
- ⁷J. A. Nevin, "The Maintenance of Behavior," in *The Study of*

Behavior: Learning, Motivation, Emotion, and Instinct, edited by J. A. Nevin (Scott, Foresman, New York, 1973), pp. 201-236.

- ⁸H. Rachlin and W. M. Baum, "Response rate as a function of amount of reinforcement for signalled concurrent response," *J. Exp. Anal. Behav.* 12, 11-16 (1969).
- ⁹G. S. Reynolds, "Some limitations on behavioral contrast and induction during successive discrimination," *J. Exp. Anal. Behav.* 6, 131-139 (1963).
- ¹⁰S. Shettleworth and J. A. Nevin, "Relative rate of response and relative magnitude of reinforcement in multiple schedules," *J. Exp. Anal. Behav.* 8, 199-202 (1965).
- ¹¹R. J. Schusterman, R. F. Balliet, and J. Nixon, "Underwater audiogram of the California sea lion by the conditioned vocalization technique," *J. Exp. Anal. Behav.* 17, 339-350 (1972).
- ¹²R. J. Schusterman and R. L. Gentry, "Development of a fatted male phenomenon in California sea lions," *Devel. Psychobiol.* 4, 333-338 (1971).
- ¹³M. Terman and H. S. Terman, "Concurrent Variation of Response Bias and Sensitivity in an Operant Psychophysical Test," *Percept. Psychophys.* 1, 428-432 (1972).
- ¹⁴A. L. Hume, "Optimal response biases and the slope of ROC curves as a function of signal intensity, signal probability and relative payoff," *Percept. Psychophys.* 16, 377-384 (1974).
- ¹⁵R. J. Schusterman, "Low false-alarm rates in signal detection by marine mammals," *J. Acoust. Soc. Am.* 55, 845-848 (1974).