Signal-detection analysis of luminance generalization in goldfish using latency as a graded response measure*

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ROC curves were determined from response latencies of goldfish in a single-stimulus generalization task. The resulting functions were similar to ROC curves obtained by rating methods with human Os.

There have been several recent studies which have essentially duplicated the standard "yes-no" or forced-choice signal-detection procedures with rats or pigeons in a variety of modalities (Hack, 1963; Nevin, 1964, 1970; Huckle & Galanter, 1966; Rilling & McDiarmid, 1965; Morrison & Morrison, 1966). With these paradigms, receiver operating characteristic (ROC), or "isosensitivity," curves may be generated by varying either reinforcement contingencies or the probability of a signal trial. These procedures are very time consuming in animal studies, and, in general, very few points on ROC curves are obtained, making interpretation of the data difficult.

An alternative to the "yes-no" and forced-choice procedures in human psychophysics is the rating method (see Green & Swets, 1966, pp. 40-43, 99-115). By allowing for several categories of response, many points on a ROC curve may be obtained in a single experimental session. Blough (1967) made the assumption that response rate in a free-operant situation indicated a pigeon's certainty that the reinforced stimulus was present. He was able to obtain up to 15 points on a ROC curve by redefining "yes" and "no" at different numbers of responses in 30-sec trials. A large number of points on a ROC curve may be generated in this way, with a great economy of experimental time.

SUBJECTS, APPARATUS, AND PROCEDURE

Two common goldfish, *Carassius auratus*, about 20 cm long, served as Ss. The details of the manipulanda and training procedure are available elsewhere (Yager & Thorpe, 1970). The fish, in a darkened light-tight tank, struck a target which caused a stimulus patch, 19 mm in diam, at the opposite end of the tank to be illuminated with one of seven luminance levels of tungsten light provided by a slide

projector in combination with Wratten neutral-density filters. The luminance values, in log millilamberts measured with a Macbeth illuminometer, are given in Table 1. The stimulus stayed on for a maximum of 5.4 sec, and there was a minimum intertrial interval of 15 sec. There was a clear Plexiglas target in front of the stimulus patch, and a response on this target during the stimulus presentation extinguished the stimulus light and ended the trial. The seven stimuli were presented in blocks of seven trials, with each stimulus appearing once in each block in random order. In addition, on an independent random schedule, each trial was followed by an additional S_4 trial with a probability of 1/16; on these trials a response on the stimulus target delivered a 20-mg fish-food pellet (Noyes Co., Lancaster, New Hampshire) into the tank. The reinforced S_4 trials were not included in the data analysis, nor was the first block of seven trials in each daily session.

An electric timer was started by the observing response and stopped by a response on the stimulus target, and (observing-target-response)-(stimulus-target-response) times were recorded by hand to the nearest 1/100 sec on each trial.

The analysis reported here was done for those training days on which the mean latency of response to S_4 was between 2 and 3 sec. This criterion was reached on 27 days, which included 346 blocks of trials, for $S\beta$ and on 19 days and 182 blocks for $S\delta$.

RESULTS AND DISCUSSION

This procedure led to good stimulus control of the fish's behavior. Fig. 1 shows the probability of response to each stimulus; as expected, the fish responded most often to S_4 , and a smooth monotonically decreasing function describes the results for both more and less intense lights. This is an example of a luminance generalization gradient.

The distributions of latencies to the seven stimuli for $S\beta$ are shown in Fig. 2. The modal latency is shortest for S_4 and is

Table 1		
Stimulus	Luminance	Values
Stimulus	Log mL	
S_1	4.02	
S_2	3.41	
S_3	2.70	
S_4^*	2.15	
S_5	1.60	
S_6	0.92	
S_7	0.87	

*Reinforced stimulus

a monotonically increasing function of stimulus difference from S_4 . There is almost complete overlap in the latency distributions for all stimuli; part of this overlap is due to response variability with a given sensory state, as well as to the variability of sensory states produced by a given external stimulus.

ROC curves were generated from the latency distribution data in the following way: S_4 was considered to be the "signal" and S_1 , for example, was considered to be the "nonsignal." One point on the ROC function was determined by letting the probability of response (Fig. 1) to S_4 be the hit rate (HR) and the probability of response to S_1 be the false-alarm rate (FAR). In other words, a response of any latency was called "yes" and no response was called "no." For the next point on the function, responses of latency < 5.3 sec were called "yes," and responses of latency ≥ 5.3 sec (including no response) were called "no." This was done repeatedly at 1/10-sec intervals, i.e., at 5.2, 5.1, . . . 0.1 sec, and hit rate and false-alarm rate were computed for each criterion latency. The same procedure was carried out considering S_2 , S_3 , S_5 , S_6 , and S_7 as "nonsignals," in turn. A variant of this method has been used previously in human auditory detection (Carterette, Friedman, & Cosmides, 1965).

Fig. 1. Probability of response to each of the seven stimuli for both Ss.

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Fig. 2. Distribution of response latencies for each of the seven stimuli, $S\beta$.

The results for $S\beta$ are shown in ROC plots in Fig. 3. It is clear that this procedure yields ROC curves that are similar in form to those obtained by the rating method from human observers (e.g., Watson, Rilling, & Bourbon, 1964; Swets, Tanner, & Birdsall, 1961).

The data are shown in double z-score coordinates in Fig. 4; also shown are the data from $S\delta$. Straight lines have been drawn by eye to fit the data best from $z(\text{FAR}) \cong \pm 1.0$; the theoretical curves in Fig. 3 are transforms of the straight lines in Figs. 4a and 4b. The data are reasonably well fit by straight lines except at low false-alarm rates; this implies that the response-time scale can be transformed monotonically in such a way as to make all the $S\beta$ distributions (shown in Fig. 2) *simultaneously* approximately Gaussian. The same holds for $S\delta$, although the transformation of response time that would be needed is not necessarily the same for these two S s. The extent to which the slopes of the lines differ from 1.0 is a measure of the lack of equality of the variances of the transformed response-time distributions.

CONCLUSION

Iso-generalization curves can be obtained by employing response latencies in a procedure similar to confidence rating methods.¹ This is a particularly useful

Fig. 3. ROC curves computed from latency distributions (see text for explanation), $S\beta$. The smooth curves are derived from signal-detection theory.

measure for animal experimentation, but has obvious application to numerous human psychophysical experiments as well. With this technique and with that of Blough (1967), a wide variety of problems in animal psychophysics can be subjected

Fig. 4. ROC curves on double z-score coordinates. The straight lines were fitted by eye. A, B: S β . C, D: S δ .

to an analysis in which the effects of response bias and motivational variables, and stimulus generalization effects, can be investigated independently. However, it is probable that response variability is at least as significant as *sensory* variability in this analysis; thus, the ROC curves obtained

cannot be used to predict *sensory* performance in other experiments.

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NOTE

1. See Green and Swets (1966, pp. 110-114) for a discussion of the comparability of yes-no, forced-choice, and rating procedures in deriving an index of discriminability.

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