Conditional discrimination in the goldfish*

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Two goldfish were reinforced for responding in the presence of a compound S+ consisting of a bright light and a loud sound. S- compounds differed from the S+ with respect to light intensity, sound intensity, or both. Responding in the presence of each compound was evaluated according to several alternative models of stimulus combination. The results permit rejection of some hypotheses concerning integrative processing in the goldfish.

The study of discriminations that involve multiple stimulus dimensions may provide considerable information about the processes underlying discriminative control. The commonly used redundant-relevant-cue paradigm focuses on the selective or attentional aspects of stimulus control; cues lying along two stimulus dimensions each predict reinforcement, but the stimuli covary (e.g., Reynolds, 1961; Kamin, 1968). Thus, neither dimension gives information not provided by the other, though the S may use both to improve its performance when discrimination is difficult (Zuckerman, 1973; Chase & Heinemann, 1972). The conditional discrimination paradigm, which is used in the present study, focuses on the integrative aspects of stimulus control. In this task, reinforcement is correlated with the joint occurrence of one value from each stimulus dimension, and no lone dimension provides adequate information.

For efficient performance of a conditional discrimination, information from at least two sources must be integrated. This suggests relatively complex processing, and performance of such a task might be expected to vary across species. The present research established a conditional discrimination in goldfish, under circumstances similar to those in which extensive data have recently been collected in the pigeon (Blough, 1972). The results permit rejection of some hypotheses concerning integrative processing in the fish.

METHOD

Subjects

The Ss were two goldfish, *Carrasius auratus*, about 6 in. long, which were experimentally naive. Each animal was housed in a separate 5-gal living tank maintained at room temperature.

Apparatus

Ss were run in a standard 5-gal aquarium which was covered during experimental sessions by a wooden lid. On the lid was mounted a Gerbrands pellet feeder which dispensed Noyes 20-mg fishfood pellets into a 6.3 x 6.3 cm square, plastic feeding ring. The ring floated on the water's surface, 20.3 cm from one end of the tank and centered with respect to the side walls. A GE1822 bulb, fixed underneath the lid, served as a secondary reinforcer. Responses of at least 0.12-N force were recorded by a

3.2 x 3.2 cm aluminum key, which was immersed into the water midway between the feeding ring and the end of the tank, about 3 cm beneath the surface of the water. The key was surrounded, on the bottom and sides, by a 3.2-cm plastic shield, which prevented accidental responses that might have resulted from swimming around or under the key. A 6-W houselight was mounted over a 3-cm translucent disk in the center of the lid.

Light stimuli were transmitted by means of a fiber-optics light guide, which was plugged into a 0.32-cm hole in the back of the response key. The other end of the light guide led to a GE1829 lamp shielded by a red plastic lens. The voltage across the lamp could be adjusted by means of a variable resistor. At the outset of training, seven light stimuli were chosen by varying these voltages from 7.5 V for Light 1 (L1) to 25 V for Light 7 (L7), in approximately equal steps. As performance improved, this range was reduced to 15 V for L1 to 25 V for L7.

Sound stimuli were produced by a Quam 8C6PAXB speaker mounted on a sheet of fiberboard and placed 2.5 cm from the end of the tank closest to the response key. A 60-Hz source was connected to the speaker through a TBL-25-S28-340 transformer, and the source voltage could be adjusted by means of a variable resistor. Seven sound intensities (S1 through S7) were chosen by varying these voltages from 1.1 V for S1 to 21.5 V for S7, in approximately equal steps.

Procedure

Ss were magazine trained by pairing the delivery of food with a 4-sec activation of the magazine light. Each fish then remained in the experimental tank overnight, with the programming apparatus set to deliver one pellet for each response. Keypressing was established in this way for both Ss without additional shaping.

Training sessions were composed of trials, as follows: After the houselight came on, a single press on the response key produced one of 49 combinations of seven lights and seven sounds. Stimulus Compound L7-S7 was designated the S+, and reinforcement was available in the presence of this compound, contingent upon four additional keypresses within 5 sec after stimulus onset. If no response occurred within this interval, the houselight was extinguished, and an intertrial interval, averaging 10 sec in length, began. If the four-response sequence was emitted in the presence of one of the remaining 48 stimulus compounds, the intertrial interval began before the 5-sec stimulus presentation had elapsed. Since previous work in this laboratory indicated that goldfish show a marked preference for responding on the basis of light, rather than sound, conditional training was preceded by seven sessions during which Ss were reinforced for responding in the presence of L7-S7, but extinguished in the presence of L7-S1.

Conditional discrimination sessions consisted of nine blocks of the 49 compounds, with stimulus presentation randomized within each block. Additional S+ compounds were inserted on an average of every 16th trial to maintain the Ss' behavior throughout the long series of S-s.

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Fig. 1. Percentage of trials, plotted on a cumulative normal scale, on which the four-response sequence was emitted as a function of sound intensity, with light intensity as the parameter.

Since both Ss learned to discriminate L7 from the remaining lights with a high degree of accuracy, the range of light values was reduced during training, in accordance with the voltages given above. Both Ss were run for 150 sessions on the conditional problem.

RESULTS AND DISCUSSION

Figure 1 shows the responding of the two fish as a function of light and sound intensity over 21 sessions, with the first block of trials for each session omitted. The proportion of trials on which the four-response sequence was emitted, plotted on a cumulative normal scale, is shown as a function of sound intensity, with

light intensity as a parameter. Figure 1 indicates that, for both Ss, more responses were emitted in the presence of the S+ (L7-S7) than for any other stimulus compound, and responding falls in a fairly regular fashion, with decreasing stimulus intensity, on each stimulus dimension.

A number of models for this sort of two-dimensional recognition task have been proposed (cf. Cross, 1965; Blough, 1972). These models specify rules that show how the effects of changes along two dimensions may combine. The rules predict responding to compounds that differ from S+ in both dimensions, from responding to compounds that differ from S+ in only one dimension. Hypothetical discriminative processes correspond to some of these combination rules. By eliminating certain rules, the present results limit the possible discriminative processes that may operate in this situation.

Perhaps the simplest way for an organism to handle a two-dimensional task would be to sample only a single-stimulus dimension on any given trial. If the selected dimension changed from trial to trial, the outcome would be an apparent control by both dimensions; however, this control would be inefficient, due to the loss of information from the "unattended" dimension. The sort of control that such a process would generate is expressed by an additive combination rule (e.g., Guttman, 1956), which states that the response decrement observed for a compound differing from S+ in two dimensions is the sum of the decrements observed when either component is varied alone. Clearly, this rule fails to describe the data in Fig. 1. When applied to the 36 compounds containing neither S+ value (i.e., neither L7 nor S7), this rule predicts fewer responses than were actually obtained for all 36 compounds for S 1, and for 26 of these for S 2. Indeed, responding "below zero" is predicted for both Ss for many stimuli that actually produced fairly high frequencies of response.

It appears, then, that the fish use information from both stimulus dimensions on many, if not all, trials. Such simultaneous use, or "integration," of stimuli might occur in many ways. A relatively simple form of integration is represented by the control of behavior on each trial solely by the "most noticeable" stimulus—that is, by the dimension differing most from its S+ value on that trial. This mode of response leads to the "dominance" combination rule, which specifies that a stimulus value on one dimension will always yield the same response whenever the other dimension takes on "less different" values. Figure 1 demonstrates that this rule also fails to describe the data. Even small changes from S+ on one dimension generally affect response frequency, no matter how large the change from S+ on the other dimension.

Another relatively simple integration scheme suggests that Ss analyze both light and sound on each trial, but

make independent decisions about each dimension. Only if both light and sound are independently judged "S+," will a response occur. This mechanism leads to a multiplicative rule: the probability of a response in the presence of a compound in which neither stimulus is at S+ is the product of the probabilities of response to compounds that vary from S+ by the same degree, but in only one dimension. Thus, the probability of a response to the stimulus compound L3-S2 would equal the probability to L7-S2 times the probability of a response L3-S7. This rule, however, predicts more than the obtained responding for 31 of 36 stimuli for S 1, and 32 of 36 stimuli for S 2.

Other combination rules may be stated, based, for example, on considerations of stimulus "distance" [e.g., the Euclidean rule (cf. Shepard, 1958)] or signal detection considerations (Heinemann & Chase, 1970; Blough, 1972), but the present data are not regular enough to enable precise specification of the applicable rule. In his analysis of similar, but more extensive data in the pigeon, Blough (1972) reported data generally consistent with those obtained here, including systematic discrepancies between the data and the additive and multiplicative rules similar to those suggested above. Blough found that when his data were plotted as in Fig. 1, they were well fit by converging straight lines; a descriptive model (multiplicative interaction) summarized this result. However, it is uncertain whether the functions in Fig. 1 are best described as a family of straight lines and, if they are, whether these lines are parallel or convergent. Also, though Blough determined an equal-interval stimulus scale, and his data support the use of the cumulative normal transform for response probabilities, it is quite possible that different stimulus and response scales would be appropriate here. Finally, additional data might make it evident that a correction for inattention

would be advisable in the present situation (cf. Heinemann, Avin, Sullivan, & Chase, 1968). Such a correction would also alter the form of the corrected curves.

In summary, we conclude that the fish integrate information from two stimulus dimensions in their performance of the present conditional discrimination. Though the data are compatible with Blough's more extensive data from similar situations in pigeons, and hence with the combination rule that describes those data, they are equally compatible with other possible models of stimulus integration.

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