Differential reinforcement of low rates in goldfish

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Four fish were trained under several values of a differential reinforcement of low rates schedule. Overall rate of responding decreased as the delay period increased. Relative rate of responding increased at longer delay periods. Conditional probabilities of responding were high shortly after a response, decreased, and then increased to maximum at about 20 sec.

Although differential reinforcement of low rate (DRL) schedules have been used in studying various aspects of schedule-controlled behavior (cf. Kramer & Rilling, 1970; Richelle, 1972), until quite recently there were few studies in which the major temporal parameter, the minimum amount of time between successive reinforced responses has been varied systematically. A wide range of species has been studied under DRL schedules, and there seems to be a very rough phylogenetic ordering in that rats and monkeys seem to be more efficient at spacing responses than pigeons and mice (cf. Kramer & Rilling, 1970; Richardson & Loughhead, 1974b; Richelle, 1972). However, the large discrepancies among experimental procedures in the various experiments make such comparisons hazardous. It does seem clear, however, that pigeons have difficulty spacing pecking responses to meet the demands of DRL schedule values of greater than about 20 sec, even though they can discriminate well such temporal intervals (Reynolds, 1966; Staddon, 1965).

Schedule-controlled behavior of goldfish is of interest because there is almost no information on behavior under various appetitive reinforcement schedules in fish (fixed ratio and fixed interval were studied slightly by Eskin & Bitterman, 1960; Hogan, Kleist, & Hutchings, 1970; and Rozin, 1964). Schedules are often used for studying other aspects of behavior and, of course, schedule-controlled behavior is of interest in its own right. Many species respond in very comparable ways under a wide range of reinforcement schedules, thus establishing great generality for schedule-controlled phenomena. However, simple DRL schedules appear to produce somewhat different behavioral adaptations in, e.g., rats and pigeons. The relative "difficulty" pigeons have in coping with keypeck DRL schedules is probably related to the kinds of species-typical responses involved in autoshaping. This is suggested by the important role collateral behaviors seem to play in DRL performance of pigeons (Richardson & Loughhead, 1974a), and by

examination of different operants (Hemmes, 1973). Since at least rats and pigeons show such different response patterns under DRL schedules, it seems important to obtain systematic data from other species in order to establish some boundaries of generality.

METHOD

Subjects and Apparatus

Four large (12-15 cm) goldfish (*Carassius auratus*) served. They had never been used in any experimental procedures and they were housed in individual 8-liter tanks which were filtered, aerated, and temperature controlled (20°-23°C). The fish received a total of 1.0 ml of semiliquid food daily (1.0 ml contains 67.5 mg of Tetramin dry fish food in a starch suspension). If this total amount was not earned during the daily test session, it was fed to the fish ½ h later. We have found this daily ration to result in fairly stable levels of appetitive responding (cf. Cochrane, Scobie, & Fallon, 1973).

Fish were trained in an apparatus similar to that described by Bitterman (1966). An intelligence panel containing a 2.5-cm-diam response key and a food nozzle located 3.5 cm below and 4.5 cm left of the response key was lowered into the animals' home tank. The entire apparatus was enclosed within a sound-shielded chamber which was itself within a sound-shielded room. The key was rear-illuminated red, and responses produced a 75-msec flash of white light added to the red. Responses were detected by a piezoelectric crystal (phonograph cartridge) attached to the response key. This velocity-sensitive transducer was calibrated to respond to a threshold force generated by a .50-g pendulum with a radius of 12 cm swinging through an arc of 14 deg. This calibration was done in air, and the key sensitivity is somewhat different in water due to its damping effect. Reinforcements were the delivery, over a 2.0-sec period, of .02 ml of the semiliquid food. The food nozzle was transilluminated white during food delivery.

Procedure

Fish were trained initially to strike the red key for reinforcement with a procedure whereby both the food nozzle and the key were illuminated red and were "live": every response to either location produced food. Free reinforcements were given until the fish began to strike the feeder reliably and then the red color was presented only on the response key and only responses to the key produced food. This procedure is easier than hand shaping and results in much faster acquisition of keypressing than simply allowing the response to emerge under regular reinforcement conditions.

On the day following keypress training and the earning of about 50 reinforcements when every response was reinforced, the fish were placed directly on the DRL schedules. The DRL schedule was the most commonly used: every response reset a timer unless T sec (the DRL value) had elapsed since the last

This research was supported by Grant MH 19961 from the National Institute of Mental Health. We thank Sarah Wright Bottjer for help with some of this work. Reprints may be obtained from the first author, Department of Psychology, State University of New York, Binghamton, New York 13901. Dennis C. Gold is now at the University of Missouri, Columbia, Missouri.

Figure 1. Mean response rate and percentage reinforcement obtained of all four fish over each phase. The first and last 5 days are plotted continuously.

response, in which case the response activated the feeder. The DRL interval following a reinforcement was timed from the end of the reinforcement. Fish were tested in daily 45-min sessions except under the 10-sec DRL condition when the session was terminated after delivery of 50 reinforcements (usually about 20 min). Two fish were trained first on the DRL 10-sec schedule, and two were trained first on the DRL 80-sec schedule. After 10 days in this initial phase, the 10-sec fish were changed to DRL 20 sec and the 80-sec fish were changed to DRL 40 sec. The entire experiment involved successive phases of DRL 10 sec, 20 sec, 40 sec, and 80 sec for two fish, and DRL 80 sec, 40 sec, 20 sec, and 10 sec for two other fish. Each phase lasted at least 10 days and not more than 15 days. Several 1-5-day breaks between successive days of testing occurred; however, they were always in the middle of a phase, and several extra test days were included in that phase to insure that responding had stabilized.

RESULTS

Overall Responding

We recorded both overall rate of responding and reinforcement and, for 3 days at the end of each phase, interresponse time distributions. The overall data, rate of responding, and percentage of reinforcement are shown combined for all four fish in Figure 1. Percentage reinforcement, an efficiency measure, was calculated as: 100 (obtained rate of reinforcement/maximum rate of reinforcement). (Maximum rate of reinforcement was six per minute for DRL 10 sec and three per minute for DRL 20 sec, etc.) These data are shown combined for all four subjects because the general patterns were very similar for all four, irrespective of the order in which they were exposed to the DRL schedule values. In Figure 1 we see that, in general, rate of responding was high at short-DRL values and progressively lower at longer DRL values. Also, as Figure 1 shows, there were no large changes in either rate of responding or efficiency (percentage of reinforcement) within phases. An examination of responding within daily test sessions showed no tendency for response rates to differ

markedly between the first half of the session and the last half.

In order to examine overall responding relative to the "optimal" rate called for by the schedule, we transformed the rate data shown in Figure 1 to percentages of the optimal rate (e.g., at DRL 20, the optimal response rate to allow collection of every reinforcement is three responses per minute). With this measure, for every fish, relative rate increased progressively as the DRL value was increased until, at DRL 80 sec, the fish responded about six times as fast as required. This result reflects, in a slightly different manner, a process similar to that shown in the percentage reinforcement data in Figure 1.

Interresponse Time Distributions

Figure 2 provides a picture of the relative frequency distribution of times between successive responses, (IRT/N), and the conditional probabilities of a response given a particular interresponse time [Anger's (1963) measure interresponse times per opportunity (IRT/opportunity)]. At DRL 10 and 20 sec, conditional probabilities, following an initial peak due to "bursts" of responding, increased progressively over the interval and reached maxima at points beyond either 10 or 20 sec, respectively. At these DRL values, all fish showed reasonably good temporal discrimination, in that responses were "withheld" for just about the required

Figure 2. Conditional probability of response (IRT/opportunity) and relative frequency of a response (IRT/N) at different times after a response. The separate panels show mean distributions taken over the last 3 days of each phase. Separate subjects are shown from top to bottom. Separate phases (and the DRL values in sec) are shown from left to right. Asterisks indicate classes for which less than 10 observations were available. The arrows point to the median interresponse time (excluding the 0-2-sec category; 0-4-sec for DRL 80).

length of time. The response bursts at all DRL values occurred at various times throughout the sessions and were not due to several responses occurring just before or after reinforcement delivery.

At the two longer intervals, DRL 40 and 80 sec, there was relatively little temporal discrimination shown except for minima in the conditional probability distributions at 3-6 sec after a response. Very few responses occurred after 27 and 34 sec under DRL 40 and 80 sec, respectively, and this is also reflected in the efficiency data of Figure 1. As was the case for overall response rate, there was no systematic relation between order of exposure to the schedule values and the interresponse time distributions. Neither increasing nor decreasing the order of exposure to the DRL values seemed to improve performance at DRL 40 or 80 sec.

DISCUSSION

The first point to be made is that goldfish respond under a DRL schedule generally in very much the same way as do other species. This may not be surprising considering the powerful control reinforcement schedules exert upon behavior of other species. However, as we noted, there is very little information about behavior under free-operant reinforcement schedules in goldfish. Response rates decreased as the DRL value increased in just the same way as they do for pigeons (Staddon, 1965) and rats (Wilson & Keller, 1953). Also, response bursts, which are seen as very high concentrations of responses in the 0-2-sec interresponse time category, and which are characteristic of DRL-controlled responding in pigeons and rats, occur in goldfish. There is little parametric data on DRL values longer than about 20 sec in pigeons. Rats do, however, appear to adapt to longer DRL values better than both pigeons and our fish (cf. Ando, 1974; Malott & Cumming, 1964; Richardson & Loughhead, 1974b; Smith & Clark, 1974; Wilson & Keller, 1953).

It is, of course, difficult to make careful comparisons across experiments and species because of differences in numerous variables, including amount of training. However, because even with exposure to an increasing series of DRL values (10-80 sec, Fish 1 and 3), our fish did not display very efficient performance at DRL 40 or 80 sec (four-six responses/min as opposed to two responses/min for Smith and Clark's rats at DRL 60 sec), we think that goldfish, as do pigeons, have difficulty optimizing at least some behaviors on these kinds of schedules. Because of the numerous situations in which organisms maximize reinforcement in a "logical" way and because of the numerous indications that the "law of least effort" is general, we think that this difficulty in behaving optimally is important.

There are at least three processes which may contribute to relative levels of difficulty in behaving

"optimally" under DRL schedules. We will mention them just briefly. First, strong species-typical responses to reinforcement may intrude into control by schedule contingencies. This kind of interaction is very clear in the case of autoshaped responses with pigeons (cf. Keller, 1974), and goldfish do display autoshaped behaviors (Woodard & Bitterman, 1974, unpublished observations in our laboratory). Second, the processes involved in the *timing* requirements of DRL of schedules may result in animals which are poorer at timing behavior (or have inadequate collateral behaviors, e.g., Richardson & Loughhead, 1974a) responding at very far from optimal levels under DRL contingencies. Third, active inhibitory processes of the sort discussed by Hearst (1972) and Rescorla (1969) may be less effective in some species than in others and result in inefficient behavior under schedules where responses must be inhibited for appropriate periods of time. At least one author (Richelle, 1972) has made this suggestion for the DRL case.

A final point is that in our experimental analysis we have not investigated directly the importance of the response-reinforcer contingency. That is, we observed only that overall response rates decreased progressively with longer DRL values. At any given DRL value, two important variables are operating: (a) the subject must wait a certain period of time before a response will produce a reinforcement, (b) reinforcements occur with a frequency roughly proportional to the DRL schedule value. Therefore, at long DRL values reinforcements tend to occur less frequently than at shorter values. It is possible that some control of response rate is due to reinforcer frequency alone and not solely to the DRL contingency. To examine the importance of the response-reinforcer contingency directly it would be necessary to devise yoked-type control conditions in which reinforcers are delivered at various frequencies either with or without the DRL contingency. Our interresponse-time data do bear indirectly on this issue. The orderly increase in response probability as time from the last response increases, at least at the shorter DRL values, suggests strongly the operation of an important operant contingency. From informal observation in our laboratory it seems unlikely that responding could be *established* by simply delivering reinforcements aperiodically without other stimulus manipulations. However, we have found no evidence in the literature which bears on maintenance of already-established responding in these sorts of situations with fish.

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(Received for publication July 1, 1974;
revision accepted December 2, 1974.)