THE RESPONSE-SHOCK-SHOCK-SHOCK INTERVAL AND UNSIGNALLED AVOIDANCE IN GOLDFISH¹

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Goldfish were trained to swim back and forth in a shuttle tank to avoid unsignalled shocks. The response-shock interval and the shock-shock interval were always of equal duration; both were either 15, 30, 45, or 60 sec. Response rates varied inversely with response-shock-shock-shock interval duration, as has been found with rats. Percentage of shocks avoided was somewhat lower at the 15 sec response-shock-shock-shock interval, but otherwise did not vary systematically with changes in the interval. As the response-shock-shock-shock interval increased, the fish made increasingly more responses than necessary to avoid all shocks. Interresponse-time distributions showed that response probability rose to a maximum at about 15 to 25 sec after a response, regardless of the response-shock-shock-shock interval. Thus, at the longer intervals the fish were responding too early in the response-shock-shock-shock interval to minimize response rates.

Recent experiments by Behrend and Bitterman (1963) and Pinckney (1968) showed that unsignalled avoidance responding can be engendered and maintained in goldfish. However, the only data on the effects of the response-shock (RS) interval, *i.e.*, the amount of time a response postpones a shock, comes from Pinckney's (1968) study of avoidance acquisition in goldfish. Studies have shown that the RS interval is a major determinant of response rate in other species and that the shock-shock (SS) interval, *i.e.*, the time between shocks in the absence of responding, is of relatively minor importance as long as it is less than the RS interval (*cf.*, Clark and Hull, 1966; Sidman, 1953, 1966).

In order to study in detail the steady-state effects of RS-SS intervals with goldfish, four fish were observed under RS-SS intervals varying from 15 to 60 sec. The SS interval was always equal to the RS interval (*i.e.*, RS-SS interval). Two fish were exposed to an ascending series of RS-SS intervals and two to a descending series, and both the response rates and the interresponse-time distributions were recorded.

METHOD

Subjects

Four goldfish, about 1.75 to 2 in. (4 to 5 cm) in length, were obtained from a local supplier and maintained in individual tanks with free

access to food throughout the duration of the experiment.

Apparatus

A plastic shuttle box similar to the one described by Behrend and Bitterman (1963) was used. The tank was 11 in. (27 cm) long overall and 5.3 in. (12 cm) wide. Each end section contained water 2.25 to 2.75 in. (6 to 7 cm) deep and the hurdle that separated the end sections was covered with 1 to 1.5 in. (2 to 3 cm) of water. The water was maintained at 21 to 23° C, and was changed every 2 to 3 weeks when excessive waste accumulated. Photocells, which detected responses, were located on both sides of the hurdle 2.25 in. (5.5 cm) apart. A response was defined as the breaking of the furthest photocell beam; *i.e.*, a complete hurdle crossing.

The tank was enclosed in a darkened sound-attenuating chamber. The only illumination came from the photocell beams. An airborne 2500-Hz, 75-db tone sounded for 30 msec after each response. Shocks of 8 v ac and 0.2-sec duration were presented through stainless steel electrodes that covered each side of the tank. Automated control and recording equipment was used.

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Procedure

Each fish was given an initial 4.5-hr training session. At first, the SS interval, *i.e.*, the time between shocks in the absence of responding, was 5 sec for all fish, but as the fish began to respond, the SS interval was increased to equal the RS interval, *i.e.*, the amount of time a response postponed shock (this was always accomplished within the initial session). After the first session, the SS interval equalled the RS interval and the daily sessions were 1 hr in duration.

Two fish (1 and 3) were initially trained with an RS-SS interval of 15 sec. They were subsequently observed for a series of sessions at RS-SS intervals of 30, 45, and 60 sec in that order. Two other fish (2 and 4) were initially trained with a 45-sec RS-SS interval and subsequently observed at RS-SS intervals of 30, 15, and 60 sec in that order. Thus, two subjects were exposed to an ascending series of RS-SS intervals from 15 to 45 sec and two were exposed to a descending series. Training at the initial RS-SS intervals continued for 14 sessions; subjects were trained for eight sessions at all the other intervals except at the 60-sec interval where training continued for 10 sessions.

RESULTS

Overall Responding

Response rates decreased monotonically as the RS-SS interval increased, regardless of exposure to the RS-SS intervals (Fig. 1). Response rate adjustment to a changed RS-SS interval was rapid when the interval was increased; it was more gradual when the interval was decreased (Fig. 2). Cumulative records of the entire terminal session at each of the RS-SS intervals show that response rates were relatively stable throughout the entire session (Fig. 3). Warm-up effects were slight and the only apparent pattern in these records is a tendency for the fish, once shocked, to take one or more shocks before resuming a stable level of responding.

The percentage of shocks avoided, computed as

$$100\left(1 - \frac{\text{shocks received}}{\text{shocks possible}}\right)$$

was about the same at all RS-SS intervals, except that at the 15-sec interval the percentage of shocks avoided was somewhat lower (Fig. 2). In general, the percentage of shocks avoided was slightly higher than that reported by Clark and Hull (1966) for comparable RS-SS intervals with rats.

The preceding data make clear that avoidance response rate, in this situation, is an inverse monotonic function of the RS-SS interval. Examination of the number of responses emitted relative to the minimum number of responses required by the schedule for the optimal behavior of avoiding all shocks suggests a relationship between the RS-SS interval and responding that is more complex. To examine relative response rates, the mean response rate over the last three days at each RS-SS interval was divided by the reciprocal of the RS-SS interval:

$$\frac{(\text{responses per minute})}{\frac{1}{\text{RS} = \text{SS interval (in minutes)}}} = \text{relative rate.}$$

Fig. 1. Response rates at each RS-SS interval for each fish. Data points are the mean of the last three days at each interval.

Fig. 2. Response rates and percentage of shocks avoided during successive daily sessions. Response rates are indicated by the solid lines and shock avoidance by the dashed lines. The data points for Day 1 are based on the last 45 min of the initial session. All other points are for 1-hr sessions. RS-SS intervals are indicated in parentheses.

This relative rate measure is 1.0 if the number of responses emitted is identical to the minimum number required to avoid all shocks. Increases in the relative rate indicate that more responses than necessary occur, and values less than 1.0 indicate suboptimal performance.

These relative rate data, shown in Fig. 4, indicate that, with the exception of the 60-sec RS-SS interval, increasingly more responses than necessary were made as the RS-SS interval increased from 15 to 45 sec. Moreover, within this range, this increase in relative rate

occurred regardless of order of exposure to the RS-SS intervals, so it did not represent a high rate carryover from a short RS-SS condition to a longer one. Note, however, that these increases in *relative rate* are not increases in *absolute rate*; absolute rate decreased as the RS-SS interval increased.

Relative rates continued to increase when the RS-SS interval was changed from 45 to 60 sec for Fish 1 and 3. Fish 2 and 4, however, whose schedules were changed from RS-SS 15-sec to RS-SS 60-sec, had lower relative rates at RS-SS 60-sec than at RS-SS 45-sec. Thus,

Fig. 3. Cumulative records from the entire last session at each RS-SS interval for each subject. Shocks are indicated as small downward marks on the response line. Numbers at the right indicate RS-SS intervals.

order of exposure to RS-SS intervals had an effect on relative rates only if the change in the interval was from 15 sec to 60 sec.

Interresponse-Time Distributions

To provide a more detailed analysis of responding, interresponse-time (IRT) distributions were recorded with class widths equal to 10% of the RS-SS interval. These data are shown, averaged over the last three sessions of each phase, in Fig. 5. Both Anger's (1963) measure, IRT per opportunity, and relative number of interresponse times (IRT/N) are shown.

At all RS-SS intervals, response probability (IRT's per opportunity) rose to a maximum at about 15 to 25 sec after the last response. Response probability then declined unsystematically at some of the longer RS-SS intervals. Probability of responding did not increase during the last half of the RS-SS interval under the longer RS-SS intervals as it did with the 15-sec RS-SS interval, and as might be expected from theoretical conceptions of unsignalled avoidance behavior (Anger, 1963). The only exception was in the data of Subject 2 at RS-SS 60-sec.

DISCUSSION

These results confirm and extend to goldfish some of the findings of earlier studies of unsignalled avoidance with rats. Over the range

Fig. 4. Relative response rates based on the last three sessions at each RS-SS interval. Each point is the mean response rate at a given interval divided by the minimum rate necessary to avoid all shocks (see text). Fish 1 and 3 were exposed to an ascending series of RS-SS intervals from 15 to 60 sec. Fish 2 and 4 were exposed to RS-SS intervals in the order 45, 30, 15, and 60 sec.

of intervals studied, rate of responding is inversely related to the RS-SS interval, as it is for rats. Moreover, goldfish learn unsignalled avoidance easily and maintain steady behavior over an extended period of time.

Although response rates decreased as the RS-SS interval increased, relative rate (relative to the minimum necessary to avoid all shocks) increased as the RS-SS interval increased. This finding is not unique. Data from rats reported by Clark and Hull (1966), Leaf (1965), and Verhave (1959) show this relationship, also. The relationship was not present, however, in the avoidance data of goldfish reported by Pinckney (1968), possibly because his data represented acquisition and not terminal levels of responding.

The higher relative rates of responding at longer RS-SS intervals are related to the form of the interresponse-time distributions. The maximum response probability (IRT per opportunity) occurred early in the RS-SS interval for intervals of 30 to 60 sec. Thus, the higher relative rates at these longer intervals were due to responding much earlier in the

Fig. 5. Relative number of interresponse times and interresponse times per opportunity as a function of time since the preceding response. Data are based on interresponse-time distributions pooled over the last three sessions at each RS-SS interval. RS-SS intervals are indicated at the top of the figure. Numbers in parentheses are the total number of responses each distribution is based on. Asterisks indicate points with less than 10 observations. The small arrows indicate mean interresponse times.

RS-SS interval than required by the avoidance schedule. Note that this effect occurred regardless of order of exposure to RS-SS intervals, unless the change in interval was from 15 to 60 sec, so it was not a carryover effect from a phase with higher response rates.

With a shuttle response, as opposed to a lever-press response, both response execution time and the time required to assume position for a response are important determinants of responding. It is possible that at the 15-sec RS-SS interval, response execution time and positioning took a substantial part of the RS-SS interval, while at longer intervals these factors were of progressively less importance in determining the form of the IRT distributions. Response execution time in the apparatus (*i.e.*, time to move between the two photo-cells) was 1 to 2 sec. This fact alone would

appear to preclude the "bursting" or high probability of very short interresponse times seen in experiments with a lever-press response where response execution time is much shorter. However, response probability did not begin to increase until about 6 sec after the last response. It is possible that this time was used in positioning for the response. Unsystematic observation of the fish did not support this interpretation. The fish seemed to be "waiting" before they made a response. However, to clarify the influence of response time on the form of the IRT distributions, data on the maximum response rate possible in the shuttle tank could be provided by an experiment with a high response-rate contingency.

In the absence of systematic data relating RS-SS intervals and interresponse-time distributions with either lever-press or shuttle

responding in other species, it is impossible to know if the results obtained here reflect basic differences between fish and other species in the mechanisms important for unsignalled avoidance or are simply reflections of similar processes.

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