Analysis of autoshaping in goldfish

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Stimulus-reinforcer and response-reinforcer control of target-striking in goldfish were studied in a series of discrete-trials experiments. Evidence of control by adventitious response-reinforcer contiguity was provided by the first experiment, which showed less response in animals given omission training than in yoked animals with the same stimulus-reinforcer experience. In the next three experiments, evidence of control by stimulus-reinforcer contiguity apart from response-reinforcer contiguity was sought in within-subjects comparisons of omission and extinction. Only the last of these experiments, in which the CS duration was short and the ITI long, showed greater response in omission. A subsidiary finding is that autoshaped goldfish respond very little, either to the CS target or to the feeder, when target and feeder are spatially discontiguous.

That target-striking in goldfish, like keypecking in pigeons (Brown & Jenkins, 1968) and lever-contacting in rats (Peterson, Ackil, Frommer, & Hearst, 1972) and monkeys (Sidman & Fletcher, 1968), can be classically conditioned was demonstrated in an autoshaping experiment by Woodard and Bitterman (1974a). The US was a drop of liquid food delivered to a small cup in the center of a target illuminated with white light, and the CS was a colored light which illuminated the target for a period of 20 sec prior to each reinforcement. Animals trained in this way struck the target in the presence of the colored light more frequently than did control animals for which the colored light and the food were explicitly unpaired. A discriminative control procedure also was used to show the effectiveness of pairing. When a light of one color was always followed by food and a light of a second color was never followed by food, all the animals responded more frequently to the first color than to the second.

While these results show the effectiveness of stimulus-reinforcer pairing, they do not, of course, require an explanation in terms of stimulus-reinforcer association. The possibility must be considered that response to the CS was initially produced by generalization from the white target-light and maintained by adventitious response-reinforcer contiguity. Our purpose in this series of experiments was, first, to look for evidence of control by adventitious response-reinforcer contiguity, and then to study the effect of stimulus-reinforcer contiguity under conditions in which response to the CS was never followed by reinforcement.

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EXPERIMENT 1

In this experiment, the hypothesis of control by adventitious response-reinforcer contiguity was tested. The strategy was to compare performance in omission (differential reinforcement of other behavior, or DRO) with performance under yoked-control conditions (which equates stimulus-reinforcer contiguity). If, as has been found in experiments with rats (Davis & Bitterman, 1971), pigeons (Schwartz & Williams, 1972), and chicks (Wasserman, Hunter, Gutowski, & Bader, 1975), yoked performance exceeds DRO performance, the difference may be attributed to adventitious response-reinforcer contiguity in the yoked condition, to adventitious contiguity of "other" behavior and reinforcement in the DRO condition, or to both.

Method

Subjects. Six 10-cm goldfish supplied by Ozark Fisheries were maintained on a 24-h feeding schedule in a large tank which was partitioned to form individual compartments and through which fresh water flowed continuously.

Apparatus. The animals were trained in a pair of small tanks through which fresh water flowed continuously from the same source as that which supplied the home tank. Each training tank contained a circular Plexiglas target, 4 cm in diameter, that could be illuminated with white, red, or green light by 7.5-W Christmas tree lamps. The target was mounted on a rod, the other end of which was clamped in the needle-holder of a phonograph cartridge whose output was used to operate a response relay (Woodard & Bitterman, 1974b). At the center of the target was a small Plexiglas cup into which liquid food (Biorell blended with tragacanth and water) could be delivered through Teflon tubing running to a syringe operated by a Peti-Pump (Harvard Apparatus Co.). All events of the experiment were programmed automatically by equipment cabled to the chamber.

Procedure. The animals were pretrained to feed from the cup located in the center of the target when the target was illuminated with white light. Each 10-sec reinforcement interval began with the onset of the white light and the delivery of a drop of food to the cup. In the first 6 sec of the interval, each drop of food was replaced as the animal took it, since contact with the cup

activated the pump. Food was not delivered in the last 4 sec of the interval to be sure that no food would remain in the cup at the offset of the light. Then discrete-trials training with red and green targets was begun, with two animals in each of three pairs working concurrently in yoked chambers. A color was presented to both animals for 20 sec on each trial. If the animal for which it was the DRO color made at least one response during the period, the stimulus terminated for both animals without reinforcement after 20 sec. Responses of the other (yoked) animal to the same color had no effect. If no response was made by the animal for which the color was on DRO, the target lights turned to white at the end of the 20-sec period and both animals were reinforced in the standard way. Red was the DRO color and green the yoked color for one member of each pair, while green was the DRO color and red the yoked color for the other member of each pair. Training continued for 20 sessions. In each session, there were 40 trials, 20 with each of the two colors presented in quasi-random order. The ITI was 10 sec.

Results

Mean rates of response to the DRO and yoked colors are plotted in Figure 1. Generalized response to both colors was relatively high at the outset and then fell off as training continued, more sharply for the DRO color than for the yoked color. Conditions by Sessions analyses of variance showed significant differences both in terms of *initial response* [$F(1/4) = 25.42, p = .007$] and in terms of *multiple responses* [$F(1/4) = 12.48, p = .024$], initial response being defined as the probability of at least one response on a given trial and multiple responses as the number of responses in the entire 20 sec. At asymptote, the probability of at least one response to the DRO color was about .5, which means that the animals were receiving about 10 reinforcements in the 20 trials with each color, while the probability of at least one response to the yoked color remained at about .9. Since stimulus-reinforcer contiguity was equal in the two conditions, the difference in performance provides

Figure 1. Mean number of responses per minute in the DRO and yoked conditions of Experiment 1.

evidence of control by adventitious response-reinforcer contiguity.

EXPERIMENT 2

That keypecking in pigeons is sustained by stimulus-reinforcer contiguity independently of response-reinforcer contiguity has been inferred from the persistence of response in omission training (Williams & Williams, 1969), but persistence alone is not critical, because (as in any classical conditioning experiment) control for the effects of the reinforcer, apart from its contiguity with the stimulus, is required. A simple solution to the problem is provided by a within-groups comparison of performance in omission and extinction; with one color on omission and a second on extinction, greater response to the omission color cannot be attributed to nonassociative effects of reinforcement. Woodard, Ballinger, and Bitterman (1974) obtained such results in a discrete-trials experiment, although precisely the opposite results were obtained in a free-operant (mult DRO EXT) experiment by Zeiler (1971). A recent discrete-trials experiment with goldfish by Bottjer, Scobie, and Wallace (1977) also showed more response in DRO than in extinction, but the results are inconclusive, since the comparison was *between* groups (rather than within groups), providing no control for nonassociative effects. We report here a discrete-trials, within-groups comparison of DRO and extinction in goldfish.

Method

Subjects and Apparatus. The subjects were 15 10-cm goldfish obtained from the same source and housed in the same manner as those of Experiment 1. The apparatus used also was the same as in Experiment 1.

Procedure. The animals were pretrained, as before, to take food from the cup at the onset of the white target light, and then they were given discrete-trials DRO-EXT training with an ITI of 10 sec. For seven animals in the Reset group, reinforcement in DRO was scheduled by a 20-sec timer which was reset by each response. When no response was made for 20 sec, the target light was changed from the DRO color (red for half the animals and green for the rest) to white, and food was delivered in the standard manner. The procedure was such, then, that the DRO color was contiguous with food on every trial. In EXT, no reinforcement was scheduled; the EXT color (green if the DRO color was red, and red if it was green) simply terminated after 20 sec. For eight animals in the No Reset group, the DRO color stayed on for 20 sec on each trial and reinforcement was given if no response was made during that time; if a response was made, the trial terminated without reinforcement. In this procedure (unlike the Reset procedure), the number of stimulus-food pairings depended on the behavior of the animal. EXT trials in No Reset were the same as in Reset. Both groups were trained for 20 sessions with 40 trials per day, 20 DRO and 20 EXT trials in a quasi-random order. The number of responses in the first 20 sec following the onset of each stimulus was measured.

Results

In the first session, the animals responded frequently to both colors, showing considerable generaliza-

Figure 2. Mean number of responses per minute in DRO and extinction for the Reset and the No Reset animals of Experiment 2.

tion from the white target light to the colored target lights. Mean rates of response to the two colors in the series of training sessions are plotted in Figure 2. The No Reset groups showed no difference ($F < 1$) either in initial or in multiple responses to the DRO and EXT colors. The Reset group made more initial responses to the EXT color than to the DRO color [$F(1/8) = 12.82$, $p = .007$] and more multiple responses, as well [$F(1/8) = 36.36$, $p = .001$]. Although rate of response to the DRO color fell off during training in the No Reset group, the animals still were receiving fewer than half the maximum possible number of reinforcements (20 per session) at the end of training. The Reset animals, of course, had 20 pairings of the DRO color and reinforcement in each session.

The only significant difference in response to DRO and EXT colors found in this experiment is in the direction opposite to that which stimulus-reinforcer association would tend to produce. If the results show anything, then, it is that a negative response-reinforcer contingency suppresses responding to the CS in these animals, perhaps by adventitious reinforcement of "other" behavior. The results do not mean, however, that the concept of stimulus-reinforcer association is to be rejected. The possibility must be considered that the effects of stimulus-reinforcer contiguity are simply not strong enough relative to the opposed effects of the negative response-reinforcer contingency to be measurable under the conditions employed (Jenkins, 1977, pp. 47-62).

EXPERIMENT 3

In this experiment, DRO and extinction responding were compared, again in a within-groups design, but the apparatus was one in which the food was delivered to a cup separate from the target rather than at the

center of the target. The purpose of the change was to make the fish apparatus more closely analogous to the conventional pigeon apparatus. Close spatial stimulus-response-reward contiguity is not, of course, necessary to maintain *instrumental* target-striking in goldfish (Engelhardt, Woodard, & Bitterman, 1973).

Method

Subjects. The subjects were eight 10-cm goldfish obtained from the same source and maintained in the same way as those of the previous experiments.

Apparatus. The animals were trained in a chamber with food delivered at a feeder located 4.5 cm to the left of the target. The feeder cup was mounted in the center of a small Plexiglas disk, 1.5 cm in diameter. During reinforcement, the disk was illuminated by a white 7.5-W Christmas tree lamp. Contacts with the feeder operated the pump (to replace food taken), as in the previous experiments. Responses to the feeder were recorded, as were responses to the 4-cm target, which, except for its lack of a food cup, was like the target used in the previous experiments and could be illuminated with white, red, or green light.

Procedure. The animals were pretrained to take food from the feeder, illuminated with white light, exactly as in the previous experiments. Then autoshaping began. There were 20 trials per session, with a mean ITI of 1 min. On each trial, the target was illuminated with white light for 20 sec, after which (independently of the animal's behavior) the target light was turned off and the feeder was illuminated with white light for the 10-sec reinforcement period. Responses to the target and responses to the feeder during the 20-sec CS-US interval were recorded separately. After 12 autoshaping sessions, the animals were given free-operant variable-time (VT) training in an experiment which is not relevant here and then switched to a discrete-trials DRO-EXT discrimination. There were 16 sessions with 40 trials per session, 20 with a red target and 20 with green in quasi-random order. For half the animals, red was the DRO color and green was the EXT color, while for the rest of the animals the opposite was true. On DRO trials, the target light was turned on and response either to the target or to the feeder reset the 20-sec DRO timer; when the animal permitted this timer to time out, the target light was turned off, the feeder was illuminated with white light for 10 sec, and food was delivered in the standard manner. On EXT trials, the target light was on for 20 sec, the feeder was dark, and no reinforcement was delivered. Responses to the target and to the (darkened) feeder in the first 20 sec after the onset of the target light on each trial were recorded. The ITI was 10 sec.

Results

In the autoshaping phase, there was little response, either to the illuminated target or to the dark feeder during the 20-sec CS-US interval; the rates were about 2/min for the target and 3/min for the feeder. In the subsequent VT training, the rate of response to the feeder increased to about 8 or 9/min, while the rate of response to the target remained low; that is, the animals responded (significantly) more at the locus of food than at the locus of the signal for food, although relatively little at either locus as compared with response under conditions of spatial stimulus-response-reward contiguity. The results of the discrete-trials DRO-EXT training are shown in Figure 3. The rate of response to the feeder established in the previous VT training, which was evident at the outset, declined over sessions, but the animals continued

Figure 3. Mean number of responses per minute to the target and the feeder on DRO and extinction trials in Experiment 3.

to respond more to the feeder than to the target. Analyses of the data for all sessions showed significantly more initial [$F(1/7) = 32.57, p = .001$] and multiple [$F(1/7) = 9.84, p = .016$] responses to the feeder.

At both the feeder and the target, the animals responded more to the extinction color than to the DRO color. The difference was significant both for initial response [$F(1/7) = 28.25, p = .001$] and for multiple responses [$F(1/7) = 22.35, p = .002$]. Here again, then, the evidence is of control by the negative response-reinforcer contingency.

EXPERIMENT 4

There is indication from work with pigeons (Terrace, Gibbon, Farrell, & Baldock, 1975; Woodruff, Conner, Gamzu, & Williams, 1977) that stimulus-reinforcer control in autoshaping is maximal where the CS-US interval is short and the ITI is long. M. E. Rashotte (Note 1) has suggested that the contradictory DRO-EXT findings of the Woodard and Zeiler experiments with pigeons, to which reference has already been made, may be understood in terms of the different temporal parameters employed. These considerations prompted a further goldfish experiment with a reduced CS-US interval and a lengthened ITI.

Method

Subjects. The subjects were 12 10-cm goldfish obtained from the same source and maintained under the same conditions as those of the previous experiments. They had been used in a study of instrumental conditioning and then rested for a period of several months.

Apparatus. The apparatus was the same as that used in Experiments 1 and 2, with the feeding cup at the center of the target.

Procedure. The animals were retrained in discrete trials to take food from the white key, after which discrimination training was begun. As in Experiments 2 and 3, there were 40 trials per session, 20 with one color and 20 with another color, in quasi-random order. For half the animals, orange was the DRO color and purple the EXT color, while for the remaining animals the relation of color to contingency was reversed. The CS duration was 8 sec and the ITI was 1 min. If the animal responded on a DRO trial, the CS terminated without reinforcement at the end of the 8-sec period; if there was no response, the DRO color changed to white at the end of 8 sec, and a 10-sec reinforcement period of the kind already described was programmed. The No Reset procedure was used here because the Reset procedure had shown more EXT than DRO responding in both previous experiments, while the Reset procedure in Experiment 2 had merely shown no difference. On EXT trials, the CS terminated after 8 sec, independently of the animal's behavior.

Results

Multiple responses to the two colors did not differ significantly ($F < 1$). The average rate of response to each color was about 40 min initially and then declined over sessions to an asymptotic level of about 15 min. At the same time, a difference in initial responses to the two colors developed. As Figure 4 shows, the mean number of trials on which the animals made at least one response was about 14 for each color in the first session. In subsequent sessions, the number declined to about 11 for the DRO color and 7 for the EXT color, a small difference, but a significant one, as shown by an analysis based on the data for all 24 sessions [$F(1/11) = 19.05, p = .001$]. Here, for the first time, then, is evidence that stimulus-reinforcer contiguity sustains target-striking in goldfish even when response to the CS never is followed by reinforcement.

DISCUSSION

The first question to be asked about these results is why omission should have produced more responding than extinction in the fourth experiment and not in the second or third. On the basis of the pigeon

Figure 4. Mean number of initial responses on DRO and extinction trials in Experiment 4.

data, it is tempting to assume that temporal variables played a critical role, although the conditions of the several experiments differed in other respects as well. It seems important now to study CS duration and intertrial interval in factorial experiments designed not only to show any interaction between them—since it has been suggested on the basis of the pigeon data that their ratio is what matters (Schwartz & Gamzu, 1977)—but also to distinguish effects on learning from effects on performance.

A more interesting question, perhaps, is how the fact that omission produces more responding than does extinction under any condition at all bears on the theory of learning in goldfish. Goldfish have been found to behave like pure S-R reinforcement animals in a rather different set of experiments dealing with the role of amount of reward in instrumental learning, studies designed to look for evidence of “learning about” reward. To account for the Crespi (1942) depression effect shown by rats trained in widely spaced trials, it seems necessary to assume that associations of some sort are formed between situational stimuli and the properties of reward, and the same assumption seems to be required in order to account for the fact that rats trained in spaced trials show less resistance to extinction after training with large reward than after training with small (Armus, 1959; Wagner, 1961). Neither of these effects is found in goldfish (Gonzalez, Potts, Pitcoff, & Bitterman, 1972; Lowes & Bitterman, 1967), which show no disruption when shifted from large to small reward and greater resistance to extinction after training with large reward than after training with small. The results of Experiment 1 are, of course, consistent with the view of the goldfish as a pure S-R reinforcement animal, and repeated failure in subsequent experiments to find more omission than extinction responding would have supported that view, but the results of Experiment 4 do not necessarily contradict it.

Whatever the implication of autoshaping experiments with pigeons for the question of stimulus-reinforcer association (Peden, Browne, & Hearst, 1977; Schwartz & Gamzu, 1977), an S-R reinforcement interpretation of the results of Experiment 4 is possible because target-striking was the measured response both to the CS and to the presentation of food. While response to the DRO color never was reinforced, the offset of the color when there was no response to it was followed almost immediately by a reinforced response to the presentation of food, a procedure that may be thought of as trace conditioning. In an apparatus like that used in Experiment 3, more omission than extinction responding to the target would provide somewhat better evidence of stimulus-reinforcer association, but response to a target separate from the feeder is negligible in the absence of an explicit instrumental contingency, and

that fact itself supports an S-R interpretation. What seems to be required is a different approach to the problem, such as might be provided, for example, by a reinforcer-devaluation procedure (Holland & Rescorla, 1975).

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