CONDITIONED REINFORCEMENT AND DISCRIMINATION PERFORMANCE¹

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Pigeons were trained in a three-key chamber to peck one side key in the presence of a vertical line on the center key and to peck the other side key in the presence of a horizontal line. Correct choice responses were reinforced with food according to fixed- and variable-ratio, fixed-interval, and differential-reinforcement-of-long-latency schedules of reinforcement. For each schedule, the birds performed under each of two conditions: (1) each correct choice response produced a brief presentation of stimuli intermittently paired with food, then the next trial; (2) each correct choice response produced an intertrial interval only. For all schedules except one long latency schedule, response rates were higher under the condition of brief stimulus presentation than under the comparable control condition. Presentation of brief magazine stimuli increased choice accuracy. The amount of change in accuracy was correlated with the rate of food presentation. Performance under the schedules with highest food reinforcement rates showed no enhancement; performance under the schedules with the lowest reinforcement rates showed the greatest enhancement.

It has been demonstrated that sequences of discriminated choice responses can be maintained when food reinforcement is presented only intermittently. These studies can be classified into two groups according to the dependency associated with those correct choice responses that are not followed by food presentation. In studies by Ferster and his associates (Ferster, 1960; Ferster and Appel, 1961; Ferster and Hammer, 1966) such correct choice responses resulted in the presentation of stimuli occasionally associated with food. Presumably such stimuli are conditioned reinforcers (Kelleher, 1966a). In the second group of studies (Cumming and Berryman, 1965; Nevin, 1967) correct choice responses that do not produce food produce an intertrial interval. Although it might be expected that such a procedural difference would result in different performances, the effects of the brief stimulus presentations on discriminative choice responding

have not, as yet, been systematically investigated.

The present study was designed to investigate the possible enhancing effects of conditioned reinforcement on the performance of pigeons on a discrimination task. As is the case with simple operants, one measure of performance is response rate. The presentation of food-associated stimuli has been found to enhance the response rate of animals on sequences of reinforcement schedules involving simple operants (Byrd and Marr, 1969; DeLorge, 1967; Findley and Brady, 1965; Hendry, 1969; Kelleher, 1966a, b; Thomas and Stubbs, 1967). Presumably, the presentation of food-associated stimuli for "correct" choice responses would enhance rate in a situation in which complex choice behaviors are reinforced intermittently with food.

In the present procedure, the effects of conditioned reinforcement on choice accuracy could also be determined. For the most part, research on conditioned reinforcement has neglected the study of conditioned reinforcement effects on choice responding (*cf.* reviews by Kelleher, 1966a; Kelleher and Gollub, 1962; Kimble, 1961; Olds, 1956; Wike, 1966). The purpose of the present experiment was to determine if the presentation of conditioned reinforcers for correct choice responses in-

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creased rate of responding, and to determine the effects of such stimuli on choice accuracy.

METHOD

Subjects

Two Silver Kings (1, 17) and three White Carneaux (3, 56, 60) pigeons, all with extensive experimental histories on a variety of tasks, were maintained at approximately 80% of their free-feeding weights throughout the experiment.

Apparatus

A three-key pigeon chamber was used. The keys were mounted in a horizontal plane 25 mm (1 in.) apart. The center key could be transilluminated by light from an in-line digital display unit (Industrial Electronic Engineers, Inc. #1820L). The side keys could be transilluminated by blue-green light. A 51-mm (2-in.) square hole directly below the center key provided access to a grain magazine. The magazine could be illuminated by a light mounted above it. The experiment was scheduled by a system of switching relays and timers; data were recorded on electromagnetic counters and a cumulative recorder.

Procedure

The birds performed the discrimination task under a variety of schedules of reinforcement. For each schedule, the birds performed both with and without the presentation of stimuli occasionally paired with food. Regardless of the reinforcement schedule, the following aspects of the procedure remained in effect throughout the experiment.

Sessions were conducted daily, each session lasting 1.5 hrs, or for fifty 4-sec presentations of grain, whichever occurred first. Session time was lengthened for the FR 50 schedule, due to the low rates of responding by the birds.

At the start of a trial, the center key was transilluminated by either a vertical or a horizontal white line on a blue-green background. The two stimuli occurred equally often and in a nonsystematic order over trials. A response on the center key resulted in the transillumination of the side keys by blue-green light. The center-key stimulus remained lighted. If the horizontal line were present, a choice response on the left side key was correct (reinforced); if the vertical line were pres-

ent, a choice response on the right side key was correct. When the conditioned reinforcement dependency was in effect, each correct response resulted in a 1-sec presentation of the magazine light. Incorrect responses were followed by a 1-sec intertrial interval during which the key lights were extinguished and responding had no scheduled consequences. When the conditioned reinforcement dependency was not in effect (control condition), both correct and incorrect responses led to the 1-sec intertrial interval. In both conditions, choice responses had no effect on which stimulus occurred on the following trial, *i.e.*, a non-correction procedure was used.

Under both conditioned reinforcement and control conditions, correct responses were reinforced with food according to six schedules of reinforcement. The first schedule was a variable-ratio schedule (VR 30) in which every thirtieth correct choice response on the average was reinforced (range-1 to 128, only correct choice responses stepped the ratio). For the VR 30 schedule, the control dependencies were in effect first, then the magazine stimulus dependencies. Next, a fixed-interval schedule was arranged in which the first correct choice response emitted after 90 sec (FI 90-sec) was reinforced (interval time was interrupted during magazine stimuli and intertrial intervals). For the FI 90-sec schedule, the magazine stimulus dependencies were scheduled first. The third schedule was a briefer fixed-interval schedule (FI 30-sec); the control dependencies were in effect first. Next, was a differential-reinforcement-of-long-latency schedule in which correct choice responses were reinforced with food if 4 sec had elapsed (DRLL 4-sec) between the transillumination of the side keys (resulting from the center-key response) and the side-key response. If a side-key response followed the onset of the side key lights by less than 4 sec, the conditioned reinforcer or intertrial interval resulted, depending on (1) the experimental condition and (2) whether the response was correct or incorrect. The magazine stimulus dependencies were scheduled first, then the control dependencies. A second differential-reinforcement-of-long-latency schedule was arranged (DRLL 8-sec) in which latencies were also timed from the center-key response; the control dependencies were scheduled first, then the magazine stimulus. Finally, a fixed-ratio schedule (FR 50) was arranged in

which every fiftieth correct choice response was reinforced. The magazine stimulus dependencies were scheduled first, then the control dependencies.

For each condition each bird was run until its choice response rate and accuracy of performance showed no consistent trend over at least five sessions. Number of sessions ranged from 12 to 50, with an average of about 20.

RESULTS

Figure 1 and Table 1 show the effects of magazine stimulus presentations on rate of choice responding. Rates were determined by dividing the total number of choice responses by session time exclusive of magazine stimulus, intertrial interval, and food cycle times. Median response rates over the last five sessions are shown for the two conditions of each schedule. Median rates are presented for each bird, and the median of the median rates of the five birds are also presented. For all schedules except the DRLL 4-sec, rates were generally higher under the magazine stimulus conditions than under the control conditions: all subjects emitted higher rates under the FI 30-sec schedule; four birds emitted higher rates under the VR 30, DRLL 8-sec, and FR 50 schedules; and three birds showed higher rates in the FI 90-sec schedule (median rates were equal for one bird). Bird 56 showed the greatest divergence from the pattern of rate enhancement: for the FI 90-sec and FR 50 schedules, only Bird 56 emitted responses at a lower rate under the magazine stimulus conditions than under the control condition. Enhancement of rate given magazine stimuli occurred over a range of response rates of 10 to 1 under control conditions.

Figure 2 shows the degree of rate change from control conditions to magazine-stimulus conditions. The points represent rates under the magazine-stimulus condition, minus rates under the intertrial interval condition for each schedule. Schedules are arranged according to their order of presentation. The observed change in rate differed among birds as well as among schedules. The smallest rate changes were observed under the DRLL schedules (whatever the direction of change). There was a slight tendency for the change in rate to be correlated with absolute response rate but this was not in evidence for all subjects.

Fig. 1. Rate of responding as a function of schedule of reinforcement. The filled bars represent performance under dependencies of magazine stimulus presentations for correct choice responses. Unfilled bars represent performance under dependencies of an intertrial interval.

Table 1
Rate of Responding (Resp/Min) for Each Bird under Each Experimental Procedure

Schedule	Condition	Bird					
			1	3	17	56	6
VR 30	Control	Mdn.	55.6	53.1*	49.2	33.9	47.5
		Range	43.2-61.4	50.3-59.9	46.7-52.2	29.9-40.5	43.1-49.8
	Magazine Stimuli	Mdn.	65.7**	52.0	60.8*	54.2**	57.3*
		Range	62.7-70.4	49.6-54.8	42.9-66.3	45.0-60.9	53.6-59.4
FI 90-sec	Control	Mdn.	34.7	31.4	34.0	26.0*	31.4
		Range	28.4-44.6	29.6-36.4	32.7-37.4	21.6-33.8	26.7-34.4
	Magazine Stimuli	Mdn.	39.4*	34.0*	43.8**	23.7	31.4
		Range	34.6-43.0	29.1-41.8	42.3-47.5	19.4-25.5	29.1-34.8
FI 30-sec	Control	Mdn.	27.8	19.2	22.0	20.4	19.2
		Range	25.6-28.4	16.5-21.5	21.6-24.0	19.1-20.7	18.4-20.3
	Magazine Stimuli	Mdn.	32.5**	24.9*	32.5**	28.4**	21.9*
		Range	30.4-33.6	20.4-30.1	27.9-34.8	24.8-32.2	20.0-22.4
DRLL 4-sec	Control	Mdn.	14.2*	12.3*	13.2*	13.2*	16.1
		Range	13.1-15.3	10.4-14.6	9.7-16.1	11.9-24.1	11.5-18.3
	Magazine Stimuli	Mdn.	12.6	10.2	11.1	12.9	16.4*
		Range	9.1-14.6	8.2-10.9	8.0-13.2	12.7-13.4	14.7-17.4
DRLL 8-sec	Control	Mdn.	7.4	5.3	9.3	5.8*	8.5
		Range	7.3-8.4	5.1-5.5	9.1-12.3	5.4-6.6	8.4-10.1
	Magazine Stimuli	Mdn.	8.2*	5.5*	11.0*	5.7	9.9*
		Range	7.4-9.3	5.0-6.7	10.2-13.0	5.6-6.2	8.4-12.4
FR 50	Control	Mdn.	4.6	1.2	18.7	14.4*	2.4
		Range	3.4-9.9	0.5-2.8	18.2-55.6	10.4-20.0	1.5-3.0
	Magazine Stimuli	Mdn.	6.0*	2.4*	25.9*	9.4	4.1**
		Range	4.3-10.1	0.3-6.0	14.1-32.5	3.5-21.4	3.5-6.4

*Indicates higher median.

**Indicates higher median and no overlap in range.

Figure 3 and Table 2 show the effects of magazine stimulus presentations on choice accuracy. Figure 3 is analogous to Fig. 1 in form; it shows median accuracy over the last five sessions for each bird and the median accuracy of the medians of the five birds. The greatest increase in accuracy under magazine-stimulus presentation occurred on the FI 90-sec and FR 50 schedules. In eight of 10 comparisons (five birds for each of the two schedules), there was no overlap in the range of accuracy scores under the two sets of contingencies. For the VR 30 and FI 30-sec schedule, the choice accuracy obtained by four birds was higher under magazine-stimulus conditions than under the comparable control dependency. However, the magnitude of difference was small. For the two DRLL schedules there was no discernible trend between accuracy measures for the two conditions.

Over most conditions and schedules, four of the five birds had accuracy scores above 0.90. Accuracy thus remained relatively constant: differences between accuracy scores un-

der both magazine stimulus and control conditions generally remained within a range of ± 0.05 . The largest differences were observed for the FI 90-sec and FR 50 schedules. Under control dependencies for these schedules, accuracy levels generally were below 0.90.

Changes in choice accuracy from control conditions to comparable magazine-stimulus conditions are presented in Fig. 4. The schedules were ordered according to a ranking of the rate of reinforcement of the six schedules. Rate of reinforcement was determined by dividing session time (exclusive of intertrial intervals and magazine cycle time) into the obtained number of reinforcements. Changes in choice accuracy by magazine stimulus dependencies were correlated with rate of reinforcement. The higher the reinforcement rate, the less was the observed change in behavior from control to magazine stimulus dependencies. Under the DRLL schedules, the subjects generally obtained two to five reinforcements per minute; under the VR 30 and FI 30-sec schedules, they generally obtained slightly

Fig. 2. Difference in rate of responding from magazine stimulus conditions to intertrial interval conditions as a function of schedule of reinforcement. The points represent rates under the magazine stimulus condition minus rates under the intertrial interval condition.

fewer than two reinforcements per minute, and under the FI 90-sec and FR 50 schedules, the subjects received one reinforcement approximately every 1.5 min (FI 90-sec) and every 2.5 min (FR 50). The specific median reinforcement rates are presented for each bird in Table 3.

Changes in rate of responding and choice accuracy were not necessarily related to an increase in reinforcement rates from the control condition to the magazine stimulus condition. Under the FI schedules, for example, both rate and accuracy increased, yet the rate of reinforcement was not substantially affected.

Cumulative records of choice responses are presented in Fig. 5. In the present situation, patterns of responding were similar to the patterns of responding on comparable schedules involving simple operants (Ferster and Skinner, 1957). The similarity held regardless of the presence or absence of the conditioned reinforcement dependency in the present situation. Under the VR 30 schedule, responses

Fig. 3. Choice accuracy as a function of schedule of reinforcement. The filled bars represent performance under dependencies of magazine stimulus presentations for each schedule. Unfilled bars represent performance under dependencies of an intertrial interval. The data are median accuracies for each bird and the median accuracy taken from the five medians for each bird.

were emitted at a high and constant rate. Under the FI schedules, responding accelerated over the interval. Under the DRLL schedules, responses were emitted at a low, constant rate. This low rate of choice responses was correlated with the emission of a number of additional responses on the center key following the onset of the side keys (*cf.* Hodos, Ross, and Brady, 1962; Laties, Weiss, Clark, and Reynolds, 1965; Laties, Weiss, and Weiss, 1969). Under the FR 50 schedule, performance typically was characterized by a long pause at the beginning of each FR, followed by a high constant rate once responding began. Under the control schedule, pauses sometimes oc-

Table 2
Probability of a Correct Choice Response for Each Bird under Each Experimental Procedure

Schedule	Condition	Bird					
			1	3	17	56	6
VR 30	Control Magazine Stimuli	Mdn.	0.976*	0.917	0.902	0.983	0.817
		Range	0.971-0.979	0.913-0.936	0.878-0.949	0.938-0.993	0.729-0.826
		Mdn.	0.974	0.980**	0.996**	0.997*	0.832*
		Range	0.954-0.987	0.948-0.990	0.984-0.999	0.991-0.998	0.802-0.863
FI 90-sec	Control Magazine Stimuli	Mdn.	0.836	0.838	0.934	0.914	0.839
		Range	0.823-0.865	0.8.8-0.904	0.689-0.970	0.889-0.944	0.820-0.919
		Mdn.	0.924**	0.973**	0.989**	0.980**	0.865*
		Range	0.915-0.944	0.959-0.987	0.977-0.933	0.962-0.985	0.806-0.880
FI 30-sec	Control Magazine Stimuli	Mdn.	0.932	0.959	0.912	0.734	0.940*
		Range	0.876-0.941	0.925-0.963	0.892-0.965	0.659-0.795	0.894-0.953
		Mdn.	0.935*	0.966*	0.949*	0.849**	0.886
		Range	0.927-0.964	0.956-0.977	0.912-0.950	0.808-0.906	0.841-0.938
DRLL 4-sec	Control Magazine Stimuli	Mdn.	0.816	0.927*	0.939	0.977**	0.918
		Range	0.752-0.849	0.911-0.934	0.833-0.967	0.964-1.00	0.901-0.980
		Mdn.	0.936**	0.876	0.992**	0.894	0.948*
		Range	0.905-0.956	0.872-0.916	0.984-1.00	0.865-0.938	0.932-0.955
DRLL 8-sec	Control Magazine Stimuli	Mdn.	0.977*	0.967*	0.624	0.924*	0.858
		Range	0.954-0.984	0.897-0.989	0.543-0.726	0.875-0.946	0.808-0.917
		Mdn.	0.962	0.953	0.654*	0.886	0.895*
		Range	0.940-0.972	0.888-0.989	0.623-0.668	0.875-0.925	0.862-0.899
FR 50	Control Magazine Stimuli	Mdn.	0.630	0.773	0.800	0.831	0.786
		Range	0.611-0.728	0.744-0.799	0.797-0.844	0.780-0.933	0.751-0.802
		Mdn.	0.934**	0.905**	0.973**	0.960**	0.851*
		Range	0.915-0.944	0.842-0.913	0.968-0.986	0.946-0.971	0.793-0.886

*Indicates higher median.
**Indicates higher median and no overlap in range.

Table 3

Median rate of food reinforcement (reinf/min) for each bird under each experimental procedure.

Schedule	Condition	Bird				
		1	3	17	56	6
VR 30	Control	1.81	1.62	1.50	1.11	1.28
	Magazine Stimuli	2.14	1.70	2.01	1.73	1.61
FI 90-sec	Control	0.59	0.60	0.60	0.57	0.59
	Magazine Stimuli	0.62	0.59	0.63	0.57	0.58
FI 30-sec	Control	1.80	1.72	1.75	1.70	1.72
	Magazine Stimuli	1.84	1.70	1.77	1.84	1.75
DRLL 4-sec	Control	3.77	1.86	4.23	3.75	1.53
	Magazine Stimuli	5.14	3.99	5.40	3.45	3.47
DRLL 8-sec	Control	2.84	3.27	1.49	2.91	1.96
	Magazine Stimuli	2.90	3.04	1.42	2.27	2.37
FR 50	Control	0.05	0.02	0.30	0.22	0.05
	Magazine Stimuli	0.10	0.04	0.50	0.17	0.07

curred other than at the beginning of the ratio, but pausing was most frequent at the beginning. The degree of pausing, particularly under the control FR schedule, was much higher than normal on simple FR 50 schedules. The pauses occurred before a center-key response was emitted. Similar patterns to those shown in Fig. 5 were obtained for all subjects.

DISCUSSION

The present results indicate that rate of responding of pigeons on a discrimination task was increased by the presentation of food-associated stimuli. Choice accuracy was similarly affected under schedules in which food reinforcement rate was relatively low.

Rate increases were very slight or did not occur on the DRLL schedules. This finding is not surprising, since high rates of responding are not reinforced on DRLL schedules; high rates increase the frequency of magazine stimulus presentations but simultaneously decrease

Fig. 4. Difference in choice accuracy from magazine stimulus conditions to intertrial interval conditions as a function of schedule of reinforcement. The points represent accuracy under magazine stimulus dependencies minus accuracy under intertrial interval dependencies. Schedules are ordered according to decreasing reinforcement rate.

the frequency of food reinforcement (Thomas and Stubbs, 1967). The increases of rates in the present discrimination task are analogous to the observed increases of rates of birds on second-order schedules (deLorge, 1967; Findley and Brady, 1966; Kelleher, 1966a, 1966b; Thomas and Stubbs, 1967).

The present study extends the findings of the effects of food-paired stimuli on the performance of animals by demonstrating changes in choice accuracy. Not only does the magazine stimulus dependency increase the probability of the emission of a response, but also increases the probability that the choice response will be correct.

The effectiveness of the magazine stimulus dependency on accuracy was related to the frequency of food reinforcement. The relation between the effects of the conditioned-reinforcement dependency and frequency of reinforcement parallels the findings of Ferster and Appel (1961), who showed that timeout presentation for incorrect responses was more effective in reducing errors when the rate of food reinforcement was low. Possibly the effects of other choice-response dependencies (such as shock) would be a function of reinforcement rate (*cf.* Azrin and Holz, 1966).

Increases in rate of responding from control to conditioned reinforcement conditions were

Fig. 5. Portions of cumulative records for Bird 1 under different reinforcement schedules: VR 30, FI 90-sec, DRLL 8-sec, and FR 50. For the records on the top, correct responses produced the magazine stimulus (or food); for the records on the bottom, responses produced an intertrial interval (or food). Each choice response stepped the response pen. Downward deflections represent food presentations. The recorder motor stopped during intertrial intervals, magazine stimulus presentations, and food cycles.

not observed to vary with reinforcement rate. Possibly, if other schedule values were chosen and reinforcement rates were higher (e.g., as in a VR 3), a functional relation might be established between reinforcement rate and response rate enhancement.

In the present study, accuracy levels differed very little among schedules, at least when the magazine stimulus dependency was in effect. This result differs from that of Ferster (1960), who found that reinforcement schedule had marked effects on choice accuracy in a matching-to-sample task. In the present study, subjects were trained first on the VR schedule, which generated a high level of accuracy. Possibly the high level of choice accuracy carried over to the subsequent schedule performance. However, Ferster demonstrated that schedule effects on matching accuracy were not dependent on past accuracy levels. Ferster's procedures differed from the present procedures in three respects: (1) Ferster employed different stimuli (colors); (2) he used a correction procedure (that is, a problem recurred on successive trials until a correct choice response was emitted); and (3) he used a matching-to-sample paradigm. It is possible that the difference between the present results and those of Ferster arose from differences in the choice response required in the two situations. In the present study, the choice response was spatially determined, i.e., right-left. In the matching-to-sample task, the choice response is determined by the stimulus that matches the sample, with the correct stimulus sometimes appearing on the right and sometimes on the left. The difference in choice accuracy of pigeons with either spatial or non-spatial choice responses has been demonstrated, even with all other aspects of the experimental task remaining the same (Smith, 1967).

Presumably, the magazine stimulus served as a conditioned reinforcer due to intermittent pairing with food. Whether intermittent pairing with food was a necessary condition for changes in performance in relation to control performance was not determined. One might argue that the presentation of different stimuli, not paired with food, one stimulus for correct choice responses and the other for incorrect choice responses might have been a sufficient condition for change (cf. Neuringer and Chung, 1967). In the present study there was no way of separating the effects of differ-

ential stimulus presentations from the effects of presentation of food-paired stimuli. Any stimulus presented after a correct response would have a close temporal relation to food because of the high response rates. The separation between choice responses would be small (less than 1 sec for most of the schedules observed in the present study) and hence so would be the separation between the contingent stimulus and food. Such a delay could lead to changes in performance that are related to an indirect pairing of a stimulus and food (Stubbs, 1969).

When performance is compared under conditions including the presence or absence of food-paired stimuli, differences in performance have generally been conceptualized as being due to the enhancing effects of conditioned reinforcement. Thus, in the present study, the effect of the magazine stimuli has been spoken of as enhancing both rate and accuracy of choice responding. Alternatively, however, differences in performance could be spoken of in terms of decrements in performance. In the present experiment, for example, accuracy levels generally were above 0.90 under all schedules except the FI 90-sec and FR 50 control schedules. Accuracy could be spoken of as being nearly asymptotic across schedules; but under certain conditions (lack of magazine stimuli coupled with a low reinforcement rate) a decrement in accuracy may occur.

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