STIMULUS CONTROL WITH FIXED-RATIO REINFORCEMENT¹

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Pigeons were trained on a three-stimulus simultaneous discrimination with reinforcements given on fixed-ratio schedules ranging from one response per reinforcement to 205 responses per reinforcement. Responses to any of the three stimuli advanced the ratio, but, when it was completed, a reinforcement followed a response to one designated stimulus. Throughout the ratio, the birds responded mainly to the designated stimulus. The relatively few responses to the other stimuli usually occurred immediately after postreinforcement pauses. The distribution of responses to the various stimuli was not affected by omitting reinforcements.

Stimulus control means that the probability of a response is related differentially to particular stimuli. In cases involving the simultaneous presentation of several stimuli, such control can be reliably obtained by reinforcing responses to one stimulus and not reinforcing responses to others. Although many data show that a reinforcement for each response to a particular stimulus establishes differential responding, there is less information about the effects of schedules that require several responses for each reinforcement. Fixed-ratio (FR) schedules of intermittent reinforcement appear to be effective: Nevin (1967) obtained differential responding to different brightnesses with a schedule involving five responses per reinforcement (FR 5), several experiments (Dews, 1963; Ferster, 1960; Mintz, Mourer, and Weinberg, 1966; Nevin, Cumming, and Berryman, 1963) obtained accurate matching-to-sample with schedules ranging as high as FR 95, and Rohles (1961) produced responses to the odd member of a set of stimuli with ratios up to FR 19.

None of these studies of fixed-ratio schedules, however, examined a simple discrimination in a situation permitting continuous responding. Nevin's (1967) study used discrete trials with a trial terminated either by each response, or after a brief period of no responding. The other research involved the complex

matching-to-sample or oddity procedures in which the correct stimulus at any time depended on the sample, thereby correlating a different stimulus with reinforcement at different times. The purpose of the present experiment was to study the effects of fixed-ratio schedules on a free-operant simultaneous discrimination among three different stimuli.

The fixed-ratio schedules used in this study of stimulus control differed from those of earlier studies. The earlier research differentially reinforced responses to the correct stimulus throughout the ratio, since only such responses counted toward fulfilling the requirements for reinforcement. Data indicating less accurate matching-to-sample with fixed-interval as compared to fixed-ratio schedules (Dews, 1963; Ferster, 1960) suggested that the differential reinforcement of all responses could be an important factor in controlling the distribution of responses to the stimuli. With the interval reinforcement, responses to the various stimuli were irrelevant except when the interval was completed. The high level of accuracy established with the fixed-ratio schedules may have been due to the requirement that responses be made throughout the ratio, or to the more stringent requirement that responses be made to the positive stimulus throughout the ratio. The more stringent form of the requirement was eliminated in the present study. Reinforcements always followed a response to a particular stimulus, but, before the end of the ratio, responses to any stimulus counted towards fulfilling the ratio requirement. The frequencies of responding to each

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stimulus throughout the ratio described the stimulus control established with fixed-ratio schedules when only the last response in the ratio had to be a certain stimulus.

METHOD

Subjects

Five adult Carneaux pigeons were maintained at 80% of their free-feeding weights throughout the experiment. Birds 15, 16, and 17 had experimental histories with a variety of procedures; Birds 45 and 55 had not been used in other research. The birds were tested daily except for weekends and occasional holidays.

Apparatus

The experimental chamber was modified from that described by Ferster and Skinner (1957). Three translucent 38-mm diameter response keys, each operated by a peck with a minimum force of 12 g, were mounted 64 mm apart, center to center. A 50-mm square aperture below the middle key provided occasional access to mixed grain. The aperture was illuminated with white light when grain was available. For most of the experiment, each reinforcement was 9-sec access to grain; in the early sessions the cycle was 4 sec. The keys and the reinforcement light, when operated, provided all illumination in the chamber.

A slide projector transilluminated all three keys with white light or each key with either a red, yellow, or blue light. The six possible spatial orders of the key colors (RYB, RBY, BYR, BRY, YRB, YBR) were programmed in

a mixed sequence with approximately equal frequency by 100 slides. Slides changed after each reinforcement.

Relay circuitry, digital counters, and a cumulative response recorder located in an adjoining room automatically controlled and recorded experimental procedures. White noise in the experimental chamber masked extraneous sounds.

Procedure

Each bird was shaped to peck at all three keys. At this time the keys were transilluminated with white light and each peck was reinforced.

Table 1 summarizes the sequence of schedules used in discriminative training for each bird.

Birds 16, 17, and 45. The three colors were projected on the keys. Reinforcements followed a response to one color (the positive stimulus or S+) and never followed a response to the other two colors (the negative stimuli or S-), but pecks to any color advanced the fixed-ratio (FR) programmer. When the bird completed one response fewer than the designated ratio, a reinforcement followed the next response to S+. The color of the positive stimulus differed among birds but was constant for each bird throughout the experiment, with an exception noted below.

The schedules used were FR 1, FR 5, FR 9, FR, 17, FR 33, FR 49, FR 65, FR 85, FR 105, FR 125, FR 145, FR 185, and FR 205. Initially, the schedule was FR 1 so that each S+ response was reinforced. After several sessions with FR 1, each bird had one day with FR 5, one

Table 1
Sequence of Schedules in Discrimination Training

Phase	Discrimination Training Starting with FR 1			Discrimination Training Starting with High Fixed Ratios	
	Sequence of Schedules			Sequence of Schedules	
	Bird 16	Bird 17	Bird 45	Bird 15	Bird 55
1	FR 1	FR 1	FR 1	FR 85	FR 65
	FR 5	FR 5	FR 5	FR 125	FR 65-145
	FR 9	FR 9	FR 9	FR 65-125	FR 125
	FR 17	FR 17	FR 17	FR 33-65	FR 125-205
				FR 33-85	FR 185
				FR 49-85	
				FR 85	
2	FR 17, FR 33, FR 49, FR 65, FR 85, FR 105, FR 125, FR 145, FR 185, FR 205 in ascending and descending orders				None
3	Extinction		None	Extinction	None

day with FR 9, and then at least three days with FR 17. No ratio lower than FR 17 was used subsequently. Schedules of FR 17 and FR 33 were studied for a minimum of three, and usually for five or more days, before being changed; schedules above FR 33 were maintained for at least five days and occasionally were kept constant for 15 or 20 days. The various fixed-ratios were used in both increasing and decreasing orders of size so that each was studied several times. Sometimes a large ratio (FR 105, FR 145, FR 185) immediately preceded or followed a small ratio (FR 17, FR 33, FR 49), but typically the ratios were used successively in order of size.

Birds 15 and 55. The ratios were increased with the keys transilluminated with white light. Responses to any key advanced the count and produced a reinforcement when the ratio was completed. Over a period of 54 days the ratio was increased to FR 85 for Bird 15; by 48 days the ratio was FR 65 for Bird 55.

The colors were then projected on the keys and the two birds received the procedure described for Birds 16, 17, and 45. The difference between the procedures was that Birds 15 and 55 were exposed initially to the three colors and the discriminative contingencies with either FR 85 or FR 65 schedules after responding with these ratios developed with the white keys.

Bird 55 had five days with the colors on the keys, the schedule varying from FR 65 to FR 205. Since the bird was then dropped from the experiment, no data were collected with repeated exposures to each fixed ratio. Bird 15 had 10 days with schedules varying from FR 33 to FR 125. The schedule was then reduced to FR 17, and the ratios were changed every several days as was done with Birds 16, 17, and 45.

Additional procedures. For the last three months of the experiment, a timeout followed each reinforcement. In the timeout, the keys were dark for 1 min and responses had no programmed consequences. The data for these sessions are not shown separately, since they did not differ from the earlier sessions without the timeout.

After Bird 16 had ratios from FR 1 to FR 125 with yellow as S+, the S+ was changed to blue for four days. The original conditions with yellow as S+ were then reimposed and maintained for the rest of the experiment.

For Birds 15, 16, and 17 the experiment ended with 15 sessions with no responses reinforced by food. These extinction sessions began after days with FR 145 reinforcement for Birds 16 and 17 and FR 105 for Bird 15. The first two days of extinction included a 1-min timeout and a change of stimulus positions on the same schedule as on the last day with food reinforcement. There was then one day with a timeout after every 125 responses for Birds 16 and 17 and every 85 responses for Bird 15. For 12 additional days responses had no effects at all: the colors remained in the same positions throughout the session, there were no timeouts, and no reinforcements. No extinction data were collected for Bird 45.

Each session terminated after either 60 reinforcements or after approximately 90 min; with schedules above FR 33, the birds obtained 60 reinforcements infrequently. Extinction sessions lasted 60 min.

RESULTS

Both the development and the maintained level of stimulus control are relevant to the relation of fixed-ratio reinforcement to simultaneous discriminations. The acquisition of the discrimination illustrated the development of stimulus control; the degree of stimulus control with continued exposure to each set of contingencies revealed the steady-state behavior. The acquisition phase for Birds 16, 17, and 45 occurred with FR 1 reinforcement; 100% S+ responses occurred by the first day for Bird 16, the second day for Bird 17, and the third day for Bird 45. Since stimulus control was perfect after the training with the FR 1 schedule, information could be obtained only about maintenance of the discrimination rather than about acquisition with intermittent reinforcement. Birds 15 and 55, exposed initially to the three colors with FR 85 and FR 65 schedules, showed the course of acquisition when there was no prior training with continuous reinforcement. Since they were responding to the white keys with intermittent reinforcement, they made it possible to observe the formation of the discrimination with sizable fixed ratios. The maintained steady-state level of stimulus control was analyzed by the prolonged and repeated exposures of Birds 15, 16, 17, and 45 to each fixed ratio.

*Acquisition of Stimulus Control with Intermittent Reinforcement:
Birds 15 and 55*

Figure 1 shows the development of responding to S+ by Birds 15 and 55. The schedules used on the acquisition days are shown above the abscissa. Responding to S+ accounted for over 80% of the total responses for both birds by the second day and subsequently for between 96% and 100%. Informal observations on the first two days suggested that responses to the negative stimuli occurred in the early part of each session and were always to one position. Once these responses to position disappeared, control by the color correlated with reinforcement developed almost immediately.

Fig. 1. Percentage of S+ responses on each day. The schedule or range of schedules used on each day are indicated above the abscissa.

Although the percentage of S+ responses rose quickly and stabilized at a high level, the number of reinforcements per day varied. On the five days, Bird 55 obtained 6, 40, 37, 24, and 35 reinforcements, and on the nine days, Bird 15 obtained 36, 23, 14, 42, 60, 55, 53, 12, and 2 reinforcements. (Bird 15 did not respond at all on the tenth day). The number of reinforcements was independent of the schedule for Bird 55. Bird 15, however, was sensitive to the prevailing ratio. Responding decreased whenever the ratios were above FR 65. In order to maintain responding on days 3 to 7, and at the same time to obtain data with high ratios, the schedules were changed during the sessions. The day began with the lower ratios and the schedules were raised gradually. The same procedure was followed on days 2 and 4 for Bird 55 in order to get that bird up to high ratios.

These data showed that stimulus control was obtained rapidly with fixed-ratio reinforcement; both birds attained over 90% S+ responses without ever having ratios under FR 65 with the stimuli present. In addition, Bird 15 revealed that although the probability of responding was affected by particular schedules, the responses that did occur were predominantly to S+.

*Maintenance of Stimulus Control:
Birds 15, 16, 17, and 45.*

The data used to analyze maintained stimulus control were the repeated exposures to the different ratios. Since the transition days do not enter into these analyses, Bird 55 was not considered at all, and the first 10 days with the colors for Bird 15 were excluded.

Table 2
Mean Percentage of S+ Responses

Schedule	Bird 15	Bird 16	Bird 17	Bird 45
FR 1		100	95	76
FR 5		100	100	100
FR 9		100	100	100
FR 17	100	100	100	95
FR 33	100	100	100	100
FR 49	100	100	99	100
FR 65	99	100	99	99
FR 85	99	100	94	99
FR 105	93	100	95	98
FR 125	99	100	97	98
FR 145	94	100	97	97
FR 185	98	100	99	98
FR 205	98	100	98	97

Table 2 shows the percentage of S+ responses with each fixed-ratio. These data are the means of all days with each schedule. The mean values well represented the daily distribution of responses, since the range from 5% lower than the mean to 100% S+ responses encompassed at least 92% of the daily values for all birds. There was no relation between a bird's performance with one schedule and the size of the immediately preceding ratio. All pigeons revealed a high degree of stimulus control with all schedules.

In Figure 2 the median absolute number of S+ and S- responses are plotted for each fixed ratio on a logarithmic scale to allow both frequencies to be shown on the same graph. The upper curves for each bird indicate that the number of S+ responses either increased and then decreased, or were asymptotic with successive increments in the size of the ratio.

Fig. 2. Log number of S+ and S- responses with each schedule. Entries at 0 indicate 0 responses.

These curves resulted from the interaction of the ratio requirement with pausing; as the ratio became larger, more responses were required for each reinforcement, and, at the same time, the pauses after each reinforcement became longer. The cumulative records shown in Fig. 4 illustrate the interaction between ratio size and pausing. Each bird typically paused for irregular periods of time after reinforcement and sometimes stopped responding in the middle of ratios as low as FR 33. In an attempt to reduce these pauses, the food cycle was increased from 4 sec to 9 sec, but this change shortened the pauses for only one or two sessions. The postreinforcement timeout also failed to eliminate the pausing. With the higher ratios the pauses were so long that

fewer ratios were completed and, therefore, the number of responses per session declined. The daily number of responses emitted with a given fixed ratio varied greatly.

Figure 2 shows that, except for Bird 16, which rarely responded to either S- under any condition, each bird made more S- responses with ratios above FR 65 than with lower ratios. Although the number of S- responses increased with the higher ratios, there was a great deal of variability between sessions. The S- responses remained close to a constant small proportion of the S+ responses.

The S- responses of Birds 15, 17, and 45 were analyzed further; Bird 16 rarely pecked at the negative colors. Considering only days on

Fig. 3. Distribution of S- responses by quarter of the ratio.

which 1% or more of the total responses were to the nonreinforced stimuli, the percentage of the total S- responses occurring in each quarter of the ratio is shown in Fig. 3. The fourth quarter contained the extra response entailed by the various ratios. Since each bird

responded about equally to the two negative stimuli, the responses to each were combined.

Between 70% and 80% of the responses to the two nonreinforced stimuli occurred in the first quarter of the ratio; there were fewer S- responses in each succeeding quarter. Cumulative records showed that these responses usually followed the pause after reinforcement or were the first responses after pauses which interrupted the completion of the ratio. Frequently, several S- responses occurred in succession. Figure 4 shows several patterns of responding during which S- responses occurred; the records were chosen to illustrate the types of behavior observed with all of the birds. The pips on the lower traces of each record indicate S- responses; all responses cumulated in the upper traces.

Three of the four birds (16, 17, 45) revealed the patterns of responding generally considered to be typical of behavior under fixed-ratio reinforcement (Ferster and Skinner, 1957). An immediate transition to responding at a high rate followed the postreinforcement pause, and the high rate continued until either

Fig. 4. Representative cumulative records. Responses to all stimuli are cumulated in the upper traces. Pips on the lower traces indicate S- responses. The upper pen reset after each reinforcement. The recorder motor stopped during a reinforcement.

the next reinforcement or the next pause. Bird 15, however, had positively accelerated responding during every ratio higher than FR 33. Figure 4 shows that the positive acceleration occurred on days when there were S- responses. Figure 5 shows representative records with various ratios on days when all responses were to S+. Since the same positively accelerated pattern was present, there seemed to be no relation between the pattern of responding and the occurrence of S- responses.

Fig. 5. Representative cumulative records for Bird 15 for days when no S- responses were made. The pen reset after each reinforcement. The recorder motor was stopped during a reinforcement.

Reversal and Extinction

Figure 6 shows the responding on the second day for Bird 16 after S+ was changed from

yellow to blue. All responding was to blue, so the bird obtained no reinforcements. Since the same behavior continued for the four days, there were no reinforcements under the reversal condition. The amount of responding decreased over the four days and the frequency of long pauses increased. The fixed-ratio pattern resumed immediately when yellow was re-established as the positive stimulus.

Fig. 6. Cumulative record for the second day of reversal for Bird 16. All responses were to the prior S+.

The extinction sessions for all birds corroborated both the results with the reversed S+ for Bird 16 and earlier extinction data obtained unintentionally due to apparatus failures. Table 3 shows the total number of responses and the percentage of responses made to S+ on each of the 15 days of extinction. Every bird continued to make from 90% to 100% of the responses to the old S+. (On day 12 Bird 15 made only three responses, the first of which was to an S-). If timeouts were given on a fixed ratio, the patterns and distributions of responses were like those when

Table 3
Responses in Extinction

Day	Bird 15		Bird 16		Bird 17	
	Total	% to S+	Total	% to S+	Total	% to S+
1	2226	100	1202	100	1454	94
2	104	100	1352	100	1168	92
3	687	100	1431	100	363	93
4	3	100	2204	100	1099	98
5	11	100	1812	100	891	91
6	1	100	1097	100	0	—
7	1096	100	1778	100	147	99
8	0	—	7	100	18	100
9	1001	100	564	100	26	96
10	0	—	970	100	1	100
11	1	100	524	100	0	—
12	373	94	451	100	3	67
13	1	100	1	100	0	—
14	0	—	0	—	0	—
15	0	—	516	100	0	—

food was presented. A pause followed each timeout and either sustained high rate (Birds 17 and 45) or positively accelerated (Bird 15) responding, occasionally broken by pauses, persisted until the next timeout. When extinction was unbroken by stimulus changes, pauses typically followed a series of closely spaced responses. Control by the previous S+ continued until responding stopped completely. Responses to the other stimuli were either the first of a session or followed a pause.

DISCUSSION

Fixed-ratio reinforcement produced a high degree of stimulus control in a simultaneous discrimination among three quite dissimilar colors. There were few S- as compared to S+ responses even though the formal contingencies did not differentially reinforce S+ responses before the end of the ratio. The stimulus control persisted in extinction despite the decrement in the total number of responses per session.

The relative frequency of S+ responses was independent of the schedule of reinforcement, although for three of the four birds the schedules produced different absolute numbers of S- responses. (Bird 16 almost never responded to an S- under any condition). The infrequent S- responses usually came right after the post-reinforcement pause or after pauses interrupting the completion of the ratio. The occurrence of periods without responding was related to the value of the fixed-ratio schedule. With ratios lower than FR 33, the birds usually started to respond immediately after each reinforcement and completed the ratio without a break. With higher ratios, both types of pausing, as well as the absolute number of S- responses, increased. Although periods without responding were not necessarily followed by responses to the nonreinforced stimuli, all S- responses either followed a pause or were part of a closely spaced series of such responses. This observation suggests that stimulus control may be affected by whatever factors operated to generate periods without key-pecking. Nevin *et al.* (1963) reported a high positive correlation between the frequency of errors in matching-to-sample and the latency of each response. Ferster (1960) found some correlation between the time to complete a ratio and the frequency of errors, for one of two pigeons. These observations

seem similar to the current one in that, with three of four birds, errors were related to pauses, although the pause-error correlation of the present study was one-sided in that errors followed pauses but pauses did not necessarily produce errors.

Postreinforcement pauses characterized almost every segment of the longer ratios, but interruptions in completing the ratios, once responding started, were less consistent. Most of the S- responses, therefore, occurred in the first quarter of the ratio in the period immediately after the postreinforcement pause. All studies that analyzed the frequency of errors in different segments of each fixed ratio reported comparable data. Nevin *et al.* (1963) and Mintz *et al.* (1966) found that, with fixed ratios ranging from FR 3 to FR 10, matching was related to the ordinal number of the trial since the preceding reinforcement. Incorrect responses diminished with each successive trial. This finding was like the present one in that responses to the negative stimuli usually occurred in the first quarter of the ratio and then declined. Nevin's (1967) data, showing that errors occurred early in fixed ratios only when a response was required to advance the ratio, raises the question of whether the relation is between pauses and errors or between the temporal remoteness of reinforcement and errors. If the discrete trial data may be generalized to the free responding situation, Nevin's experiment suggests that the temporal relation may be the important one.

For three of the four birds, the patterns of responding in each ratio were similar to those generally considered typical of fixed-ratio schedules (Ferster and Skinner, 1957). Responding occurred either at a high rate or not at all. The fourth bird (Bird 15) displayed positively accelerated responding in each ratio; the records showed the kind of curvature usually associated with fixed-interval schedules. The distinctive pattern for Bird 15 may have been affected by the history of high ratios on three white keys, a history not shared by the other birds. The main point, however, is that the same high degree of stimulus control occurred for all birds independent of the particular patterns of responding generated by the schedules.

The fixed-ratio schedules used in this experiment were analogous to fixed intervals in that only the final response had to be to a particular

stimulus and earlier responses were not differentially reinforced. With a ratio schedule in which the ratio was advanced only by correct responses, Ferster (1960) and Dews (1963) found more accurate matching-to-sample with fixed-ratio than with fixed-interval reinforcement. The current experiment extends the other research as it indicated that fixed-ratio schedules establish strong stimulus control when only the final response is differentially reinforced. Additional research is required to discover whether fixed ratios produce better stimulus control than do fixed intervals with a simultaneous discrimination like that used in this experiment, or whether the superiority of the ratios pertains only to the complex matching task.

Nevin (1967) concluded that stimulus control, once established, was relatively independent of variables affecting the overall level of performance. The present experiment extended the generality of this conclusion, at least in the context of fixed-ratio reinforcement. Changes in schedules altered the frequency of reinforcement and the number of responses per reinforcement. Stimulus control, however, was constant whether reinforcements depended on one or many responses, and persisted when reinforcements were not available at all.

With a simultaneous discrimination with reinforcement immediately following a response, the stimulating conditions at the time

of reinforcement can be assumed to include the stimulus to which the last response occurred. The present experiment showed that when the last response was always to a particular stimulus, almost all of the responding came under the control of that stimulus. The most general conclusion about these data is that they fit Ferster and Skinner's (1957) hypothesis that the stimuli present at the time of reinforcement are critical in determining the characteristics of behavior throughout extended sequences.

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