A CONJUNCTIVE SCHEDULE OF REINFORCEMENT [1]

R. J. HERRNSTEIN [2, 3] AND W. H. MORSE

Harvard University

In a fixed-interval schedule, the event that programs the reinforcement of a response is the passage of a specified period of time without reinforcement. Reinforcement on a fixed-ratio schedule depends upon the occurrence of some fixed number of unreinforced responses. [4] The conjunctive fixed-interval, fixed-ratio schedule combines these two schedules by arranging that a response is reinforced only after the passage of the time period and the emission of some minimal number of unreinforced responses.

Figure 1 shows a schematic representation of a fixed-ratio, a fixed-interval, and a conjunctive schedule plotted on coordinates of cumulated responses and time. In each of these representations, the three diagonal lines that emanate from the origin are hypothetical examples of responses being recorded cumulatively in time. The three lines represent three different rates of responding. In the case of the fixed-ratio schedule, the horizontal line at n on the ordinate defines the value of the ratio, i. e., the number of unreinforced responses that must occur in order for a response to be reinforced. Reinforcement on a fixed ratio is therefore dependent upon the emission of a number of unreinforced responses and is independent of the passage of time. For the fixed-interval schedule, the value of the interval is defined by the vertical line at t on the abscissa. Responses that occur between zero (the origin) and time t are unreinforced; the first response after time t is reinforced. With this schedule, reinforcement is independent of unreinforced responding and depends upon the passage of time. For the conjunctive fixed-interval, fixed-ratio schedule, the relevant values are defined by the right angle at t, n. Responding prior to time t and before the emission of n responses is unreinforced. A response is reinforced after time t and the emission of n-1 unreinforced responses.

[1] The research reported in this paper took place in the Psychological Laboratories, Harvard University, with the support of a grant from the National Science Foundation, Washington, D.C.

[2] This author was a National Science Foundation Predoctoral Fellow at the time this research was performed.

[3] Present address: Walter Reed Army Institute of Research, Washington 12, D.C.

[4] In this paper, the term "unreinforced responses" refers to those responses that have no immediate and deliberately arranged consequence in the subject's environment. In the case of the fixed-ratio schedule, these responses bring the subject closer to reinforcement but are nevertheless called "unreinforced." The term "unreinforced" is therefore simply descriptive of the experimental procedure and does not imply a result of an analysis of the behavior itself.

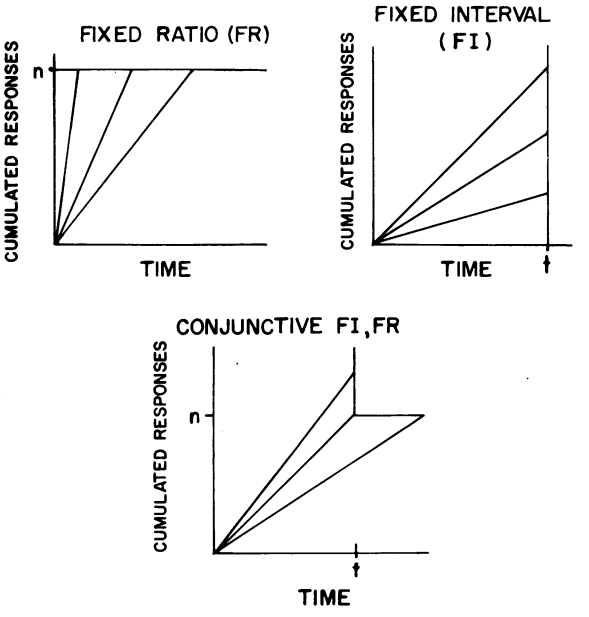

Fig. 1. Schematic representations of fixed-ratio, fixed-interval, and conjunctive schedules of reinforcement. (See explanation in text.)

For the conjunctive schedule, a single reinforcement is via either the fixed-interval or the fixed-ratio component (i. e., the cumulative record crosses either the vertical or horizontal side of the angle, respectively). The component that is effective for any single reinforcement depends upon the number of responses emitted prior to time t. If the number is smaller than n, reinforcement is via the fixed-ratio component. If it is larger than n, reinforcement is via the fixed-interval component. On the conjunctive schedule, each reinforcement is dependent upon both the passage of time and the emission of unreinforced responses.

METHOD

Subjects

The subjects were two experimentally naive, adult, male, White Carneau pigeons, which were kept at approximately 80% of their free-feeding weights.

Apparatus

The pigeons occupied two compartments of a turntable which has been described elsewhere (2). The pigeon pecked at a translucent plexiglas disk (diameter, 1 inch) which took a force of 10 to 15 grams to operate. The reinforcer (4-second access to grain) was presented through an opening beneath the response key.

Procedure

The pigeons were initially trained to eat from the grain magazine and then, for two sessions, each peck to the key was reinforced. They were then trained on a 15-minute, fixed-interval schedule. All illumination was extinguished in the experimental chamber for 5 minutes after every reinforcement. The 15-minute period is considered to begin at the termination of this "time out." After several weeks of 5-hour daily experimental sessions, the procedure was changed to the conjunctive schedule. The fixed-interval component was kept at 15 minutes while the fixed-ratio component was set at 10, 40, 120, and 240 responses for one pigeon and 40, 120, and 240 responses for the other. Each value of the ratio component was held constant for at least 50 experimental hours. The various values were investigated three times each (except for 240 responses, which was investigated only once), and the order in which the values were used was varied from one series to another. In addition, the schedule was restored to a simple fixed-interval for a period of at least 50 experimental hours three times during the experiment.

RESULTS

The effect on the over-all rate of responding of various values of the ratio requirement is shown in Fig. 2 for both pigeons. The abscissa gives the value of the

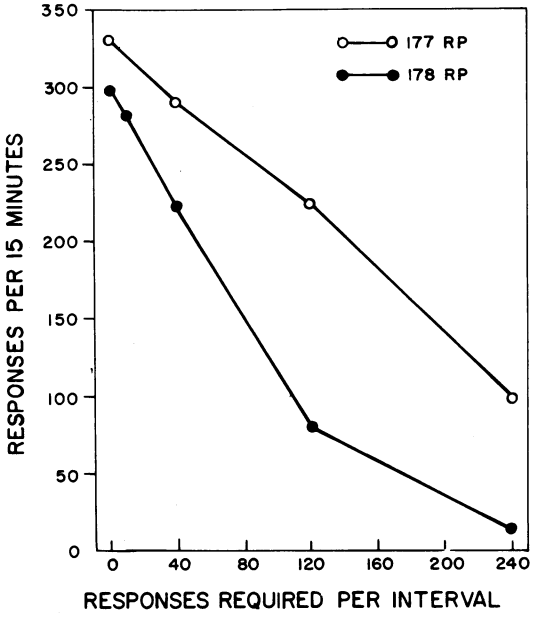

Fig. 2. Over-all rate of responding for both subjects as a function of the size of the number requirement of the conjunctive schedule. Points plotted at zero on the abscissa are for the simple fixed-interval schedule.

ratio component in the conjunctive schedule; the points plotted at zero on the abscissa are for the simple fixed-interval schedule. The ordinate shows the rate of responding during the last session for each value on the abscissa. The rate is expressed as number of responses per 15 minutes (rather than number of responses per minute or per second) in order to facilitate the comparison between number of responses required with number of responses emitted. Since each value (except 240) was used on three different occasions, these points are averages obtained from three sessions. Figure 2 shows that even ratio requirements which are much smaller than the average number of responses occurring per 15 minutes will reduce the over-all rate of responding. Only with ratio components equal to 240 responses for both pigeons and 120 responses for Pigeon 178RP has the number of responses emitted per 15 minutes fallen below the number required by the ratio component.

Figure 3 shows the effect of varying the ratio requirement on the average time between reinforcements (excluding the 5-minute time out). The data presented here were obtained from the same sessions as those used for Fig. 2. The minimum inter-reinforcement time possible is determined by the value of the fixed-interval component of the conjunctive schedule, which, in the present experiment, is held constant at 15 minutes. When reinforcement is via the fixed-interval component, the inter-reinforcement time is equal to the size of the interval plus the time to the first response after t. (See Fig. 1.) When reinforcement is via the fixed-ratio component, the inter-reinforcement time includes t plus the time taken to emit the

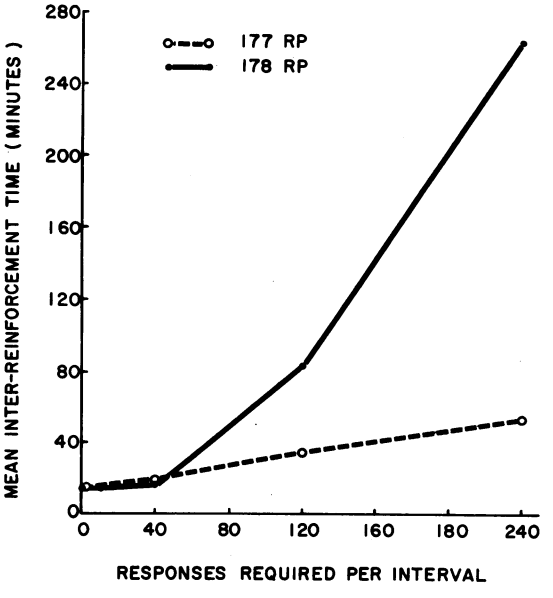

Fig. 3. Average time between reinforcements (excluding the "time out"), for both subjects, as a function of the size of the number requirement of the conjunctive schedule. Points plotted at zero on the abscissa are for the simple fixed-interval schedule.

number of responses lacking from n. As the number requirement increases, reinforcement via the fixed-ratio component becomes more and more likely. (See Fig. 2.) Figure 3 shows that this likelihood is accompanied by a lengthening of the inter-reinforcement time. Both pigeons show substantial increments in inter-reinforcement time when the ratio requirement is large, but the magnitude of the increment is much greater for 178RP than for 177RP.

Figures 4 and 5 contain portions of sessions (for 177RP and 178RP, respectively) showing the change in the fixed-interval performance after the introduction of a

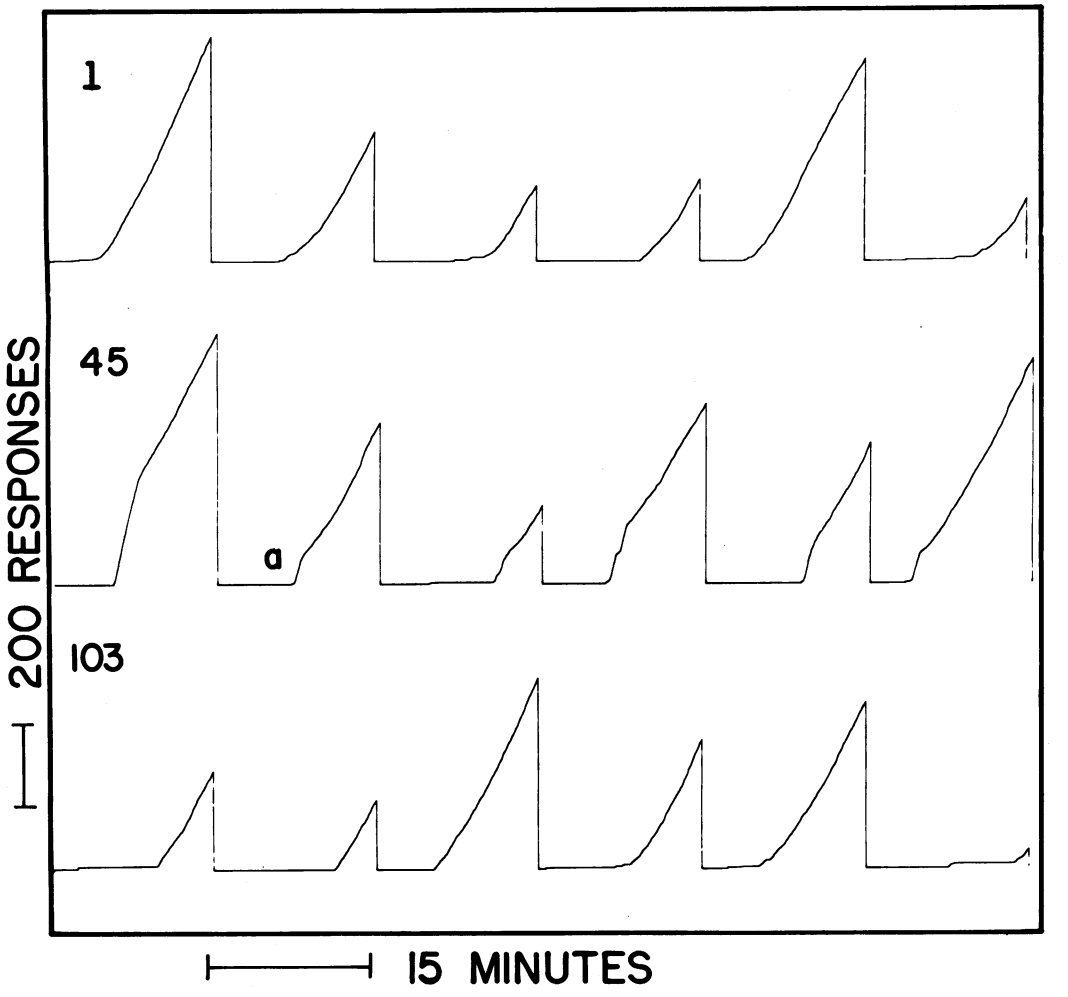

Fig. 4. Three 2-hour segments of cumulative-response curves for 177RP, with the record resetting to the base line at reinforcement. Top and bottom records are for the simple fixed interval; the middle record is for the conjunctive with a number requirement of 40 responses. Numbers at the left of each segment give elapsed experimental hours, taking the upper segment as the first hour.

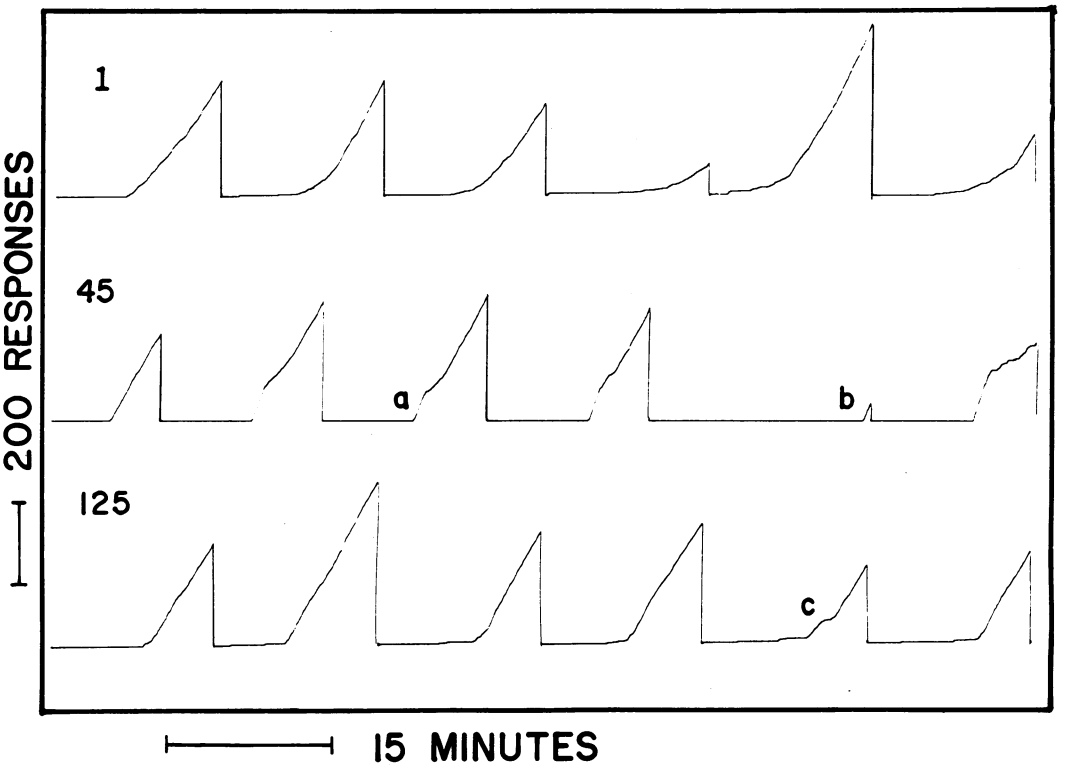

Fig. 5. Three 2-hour segments of cumulative-response curves for 178RP, with the record resetting to the base line at reinforcement. Top and bottom records are for the simple fixed interval; the middle record is for the conjunctive with a number requirement of 40 responses. Numbers at the left of each segment give elapsed experimental hours, taking the upper segment as the first hour.

ratio requirement of 40 responses and the subsequent return to the original performance after the removal of the requirement. The upper segment in each figure is a 2-hour sample of the cumulative-response record obtained during the last session of reinforcement on a simple fixed interval. The record is reset to the base line after each reinforcement and the 5-minute time-out period is not recorded. Both pigeons show the performance typical for this schedule. On the session following this record, a ratio requirement of 40 responses was added, making the schedule a conjunctive FI(15) FR(40). The middle segment of each figure shows the performance on the conjunctive 45 hours later. Both pigeons are by this time showing a stable performance which differs in at least one important way from that obtained with the fixed-interval schedule. There is no longer a gradual increase in rate of responding during each interval. Instead, the initial pause in each interval is followed by a group of responses emitted at a rate greater than that obtained with the comparable fixed-interval schedule. The letter a on each figure indicates instances of this phenomenon. Following this responding at a high rate, the curves resemble those obtained with the simple fixed interval, frequently showing positive curvature up to the reinforcement.

With a ratio requirement of 40 responses, most reinforcements are delivered via the fixed-interval component of the schedule, since the animal has usually emitted more than 40 responses by the time 15 minutes has elapsed. The one instance in these figures where reinforcement was delivered via the fixed ratio is denoted by letter b in Fig. 5. During the entire 45 hours only 16 such instances occurred for 177 RP and 22 for 178RP.

The bottom portion of Fig. 4 and 5 show the recovery of the fixed-interval performance after 58 and 80 hours, respectively, of reinforcement on a simple fixed-interval schedule. Recovery is virtually complete; a possible residual effect of the earlier ratio requirement can be seen at the letter c in Fig. 5. The bottom portion of Fig. 5 also appears to have less positive curvature than the upper portion.

The change in procedure from the conjunctive schedule with a ratio requirement of 40 responses to a fixed-interval schedule exerts its effect when the animal has emitted less than this number of responses during the 15-minute interval. The recovery of the fixed-interval performance shown in the bottom records of Fig. 4 and 5 took place after only eight such occasions for 177RP and twenty for 178RP.

Figure 6 shows an extinction curve which was obtained when the ratio requirement was 40 responses. The curve has been collapsed along the abscissa in order to present the complete 9-hour session. This curve resembles extinction after simple fixed-interval reinforcement in that it is cyclical and the transitions from responding to no-responding are gradual (1). It differs, however, in the transitions

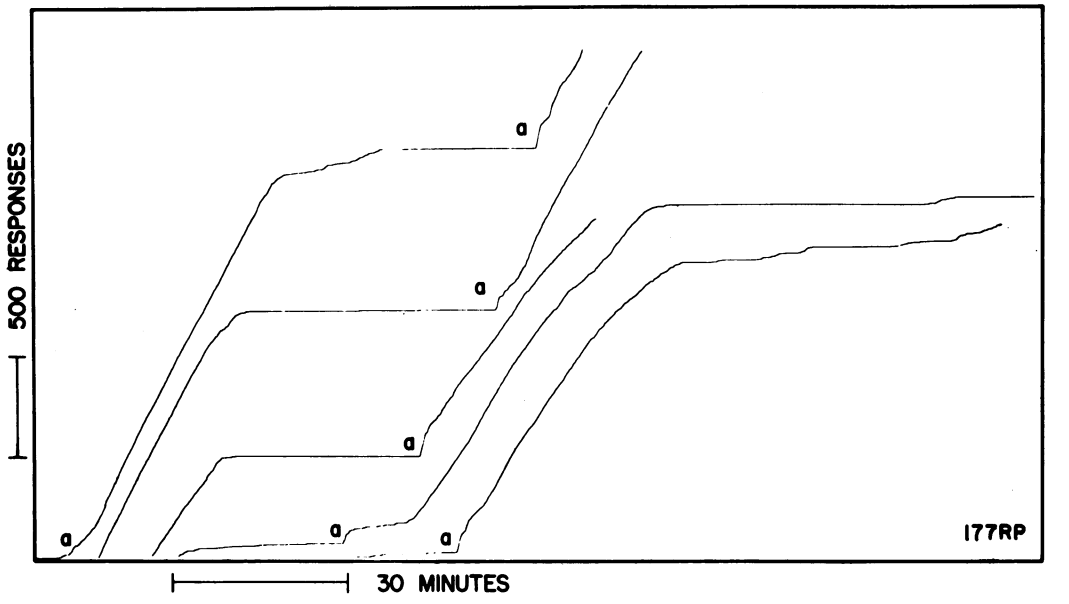

Fig. 6. Cumulative-response record of 9 hours of extinction following the conjunctive with a number requirement of 40 responses. The curve has been collapsed along the abscissa.

from no-responding to responding, which are abrupt, rather than gradual. Each cycle begins with a group of responses emitted at a high rate, indicated by the letters a in Fig. 6.

As the ratio requirement is increased to the higher values, the over-all response rate falls sufficiently low so that most of the reinforcements are via the fixed-ratio component. An example of the performance obtained with a ratio requirement of 120 responses is shown in Fig. 7 (for 178RP). Both of the 2-hour segments in this figure are for a conjunctive FI(15) FR(120). The upper and lower segments were obtained early and late, respectively, in the pigeon's exposure to this value of the ratio requirement. The upper record resembles the performance obtained when the ratio requirement is 40 responses, and all of the reinforcements, except the first, are via the fixed-interval component. The lower record, which is typical of the performance when the ratio requirement is large, closely reproduces the "strain" obtained with large values of simple fixed-ratio schedules (1). As in the latter case, the animal pauses after reinforcement for long periods of time, and when responses occur, they are emitted at a high rate. When the pause consistently exceeds 15 minutes (as it does for 178RP with ratio requirements of 120 and for both pigeons with 240), then virtually all reinforcements are delivered via the fixed-ratio components of the conjunctive schedule.

DISCUSSION

The simple fixed-interval schedule does not stipulate the emission of unreinforced responses as a condition for reinforcement. This schedule does, however, result in the occurrence of large numbers of unreinforced responses. As a matter of fact, larger numbers of unreinforced responses can be generated by using some

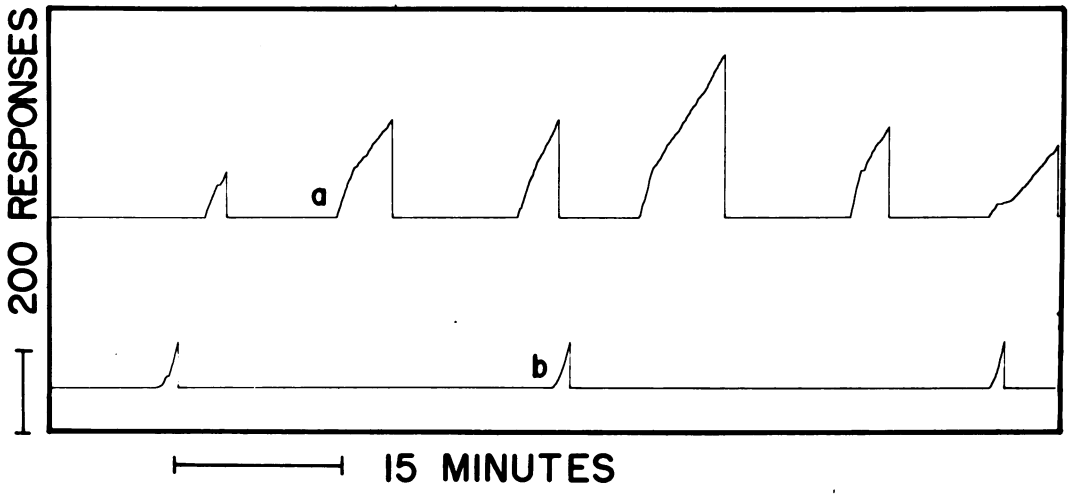

Fig. 7. Two 2-hour segments of cumulative-response records for 178RP obtained with the conjunctive schedule when the number requirement was 120 responses.

values of the fixed-interval schedule than by using any value of the fixed-ratio, even though, in the latter, these unreinforced responses are the very condition for reinforcement.

Does the number of unreinforced responses obtained with fixed intervals depend, in some way, upon the fact that this schedule does not require such responding? In the conjunctive schedule, we systematically varied the number of unreinforced responses required for reinforcement and observed changes in the output of behavior. Figure 2 showed that this output dropped steadily as the number requirement was increased. Although the pigeon was emitting, on the average, approximately 300 unreinforced responses with a simple fixed interval, a number requirement as low as 10 responses has the effect of reducing the response output.

This finding suggests the manner in which fixed-interval reinforcement generates such a large amount of unreinforced behavior. A number requirement of 10 responses per reinforcement is brought to bear on the animal's behavior only on those occasions when reinforcement is via the fixed-ratio component of the conjunctive schedule. (See Fig. 1.) If, in any one interval, the animal has emitted 10 or more responses during the 15-minute period, then the reinforcement at the termination of that interval is in every respect identical to reinforcement delivered on a simple fixed-interval schedule. Therefore, if there were no instances of reinforcement for fewer than 10 unreinforced responses on a simple fixed interval, then this value of the number requirement would have no effect. In a simple fixed-interval schedule, however, reinforcements occasionally occur after fewer than 10 unreinforced responses. It was observed, in fact, that the number of unreinforced responses per interval with the simple fixed interval varies from zero to three or four times the average number. The conjunctive schedule with a number requirement of 10 prevents the reinforcements that would otherwise have occurred for fewer responses. Increasing the number requirement increases the range over which reinforcements are prevented and is associated with further decrements in responding.

A property of fixed-interval reinforcement that contributes to unreinforced responding may be the fact that this schedule makes no requirement about such responding. In an ordinary 15-minute, fixed-interval schedule, the number of unreinforced responses associated with each reinforcement is determined entirely by the animal's own behavior. When the number is small, the probability that any response may be the reinforced response is relatively large. A high probability of reinforcement for each response can be expected to favor a large output of responding. But since the fixed-interval schedule programs reinforcement on the basis of the passage of time only, a large output of responding will serve to decrease the probability of reinforcement for any single response. A low probability of reinforcement for a response can be expected to decrease the number of responses emitted. As the level of responding falls, probability of reinforcement increases, thus permitting a repetition of the process just described. Similar accounts have been previously suggested as an explanation of the observed oscillation in number of responses per interval with fixed-interval reinforcement (1, 3). The effect on rate of responding of the number requirement in the conjunctive schedule demonstrates that those occasions in the ordinary fixed interval when reinforcement occurs after a very small number of unreinforced responses play an important role in maintaining the high over-all level of responding. The number requirement prevents the probability of reinforcement for a single response from being as high as it is on occasion in ordinary fixed-interval reinforcement, and the

average rate of responding is consequently reduced. The larger the number requirement, the smaller is the maximum possible probability of reinforcement for a single response. Figure 2 shows that this relationship is accompanied by a progressive decline in the rate of responding.

As was shown in Fig. 4 and 5, the conjunctive schedule with a small number requirement affects not only the average rate of responding, but also the pattern of responding within any interval. The difference between this performance and ordinary fixed-interval performance is probably a result of the differing stimulus conditions associated with reinforcement via the two components of the conjunctive schedule. Reinforcement will be via the fixed-ratio component only when the 15 minutes elapses with fewer than the required number of unreinforced responses. Because of the nature of the fixed-interval performance, this will most frequently occur when the initial pause in a given interval exceeds 15 minutes. Conditions therefore exist upon which a discrimination may be based. When the animal has not responded for a long time, reinforcement may be via the fixed-ratio component. Conversely, when the animal is responding, the contingency at reinforcement is likely to be that of the fixed-interval component. The initial pause sets the occasion for fixed-ratio behavior; a group of responses (whose size probably depends upon the value of the number requirement) sets the occasion for fixed-interval behavior. Thus, the animal's own behavior generates stimuli which in turn control different patterns of responding, in a manner analogous to mixed schedules (1). This would also account for the difference between the extinction curve presented in Fig. 7 and that obtained after simple fixed-interval reinforcement.

SUMMARY

Two pigeons were trained on a 15-minute, fixed-interval schedule. They were then trained on the conjunctive fixed-interval, fixed-ratio schedule, in which a response is reinforced only after the passage of a specified time and the emission of a minimal number of unreinforced responses. The period of time was kept at 15 minutes, while the number requirement was varied from 10 to 240 responses. Increasing the number requirement had the effect of decreasing the average rate of responding. The presence of the number requirement also changed the pattern of responding within the 15-minute period from that obtained with ordinary fixed-interval reinforcement.

REFERENCES

1. Ferster, C.B., and Skinner, B.F. Schedules of reinforcement. New York: Appleton-Century-Crofts, 1957.
2. Herrnstein, R.J., and Morse, W.H. Some effects of response-independent positive reinforcement on maintained operant behavior. J. comp. physiol. Psychol., 1957, 50, 461-467.
3. Skinner, B.F. The behavior of organisms. New York: D. Appleton-Century-Crofts, 1938.