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BEHAVIOR OF THE PIGEON UNDER SELF-YOKED INTERVAL AND RATIO
SCHEDULES OF REINFORCEMENT

City University of New York

PH.D. 1983

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BEHAVIOR OF THE PIGEON UNDER SELF-YOKED INTERVAL AND RATIO
SCHEDULES OF REINFORCEMENT

by

JULIAN K. ALBERT

A dissertation submitted to the Graduate Faculty
in Psychology in partial fulfillment of the
requirements for the degree of Doctor of Philosophy,
The City University of New York.

1983

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This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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Abstract

BEHAVIOR OF THE PIGEON UNDER SELF-YOKED INTERVAL AND RATIO
SCHEDULES OF REINFORCEMENT

by

Julian K. Albert

Adviser: Professor Brett K. Cole

In Exp. I, five pigeons were exposed to a mixed schedule consisting of a fixed interval (FI) component and a ratio component, in which the components changed after every reinforcement. The number of responses emitted in an FI component served as the ratio requirement in the immediately following ratio component, so that the schedules were equated for number of responses-per-reinforcer. The procedure was labeled "self-yoked," and the ratio component was called "yoked-ratio (YR)." At all values of FI (15, 30, 60, and 120 sec), response rates and post-reinforcement pauses were essentially the same in FI and YR. Experiment II consisted of mixed and multiple schedules. The multiple schedules were created by the addition of an exteroceptive stimulus (key light) to one of the schedule components. Schedule parameter values were identical to those in Exp. I. In the multiple schedules, response rates were higher and post-reinforcement pauses were shorter in YR. In the mixed schedules, behavior generally returned to its

non-differential form. Several instances of continued differential behavior in the mixed schedules was attributed to behavior still in transition; in all cases, the separation was less than under the multiple schedules. The virtual identity of behavior in FI and YR in Exp. I, and in the mixed schedules of Exp. II, demonstrates that there are conditions in which interval and ratio schedules will not produce the differences in behavior typically observed under such schedules. Those conditions consist of the following: (a) the schedules are equated in terms of number of responses-per-reinforcer, (b) schedule changes take place after each reinforcement, and (c) differential stimuli are not correlated with the schedules. It was asserted that any description of behavioral differences produced by interval and ratio schedules is incomplete without taking account of the conditions under which differential behavior does not emerge.

Acknowledgements

I wish to express my deepest gratitude to professor Brett K. Cole for his encouragement, assistance, constructive criticism, and forbearance in the preparation of this research. I wish also to thank professor William N. Schoenfeld for his invaluable support, and availability in time of need. Thanks also to professor Thom Verhave for his helpful comments.

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Introduction

The reinforcement schedules called "interval" and "ratio" differ in their specification of which response, in the specified response class, will qualify for reinforcement. An interval schedule provides for reinforcer delivery following the first response made after a specified period of time, but does not specify any particular number of responses, save one. In fixed interval (FI) schedules, the specified period between the availability of reinforcers is constant, but the period may be timed in one of two ways: (1) from the end of the preceding reinforcement, which imposes a minimum time between delivered reinforcements (Skinner, 1938); since the organism may not respond at the moment reinforcement is made available, the average time between reinforcers usually exceeds the specified minimum; and, (2) by the clock, which arranges reinforcer availability independently of behavior (Ferster & Skinner, 1957); such an arrangement does not impose a minimum time between the successive deliveries of the reinforcer, and thus the specified schedule value represents the average of a distribution of times between such deliveries; the latter distribution is not specified by the schedule, but is determined by the subject's behavior under the schedule. In variable interval (VI) schedules, the specified time of reinforcer availability is varied from reinforcement to

reinforcement, with the mean interval and distribution of intervals specified in advance (Ferster & Skinner, 1957). Under interval schedules, subjects typically respond before the interval has elapsed, and thus make "extra" responses that are not required by the schedule.

A ratio schedule arranges reinforcement following a specified Nth response, but does not specify any time requirement for the performance of the required N responses. The actual time between reinforcements is thus dependent upon how quickly the subject produces the required number of responses. In fixed ratio (FR) schedules, the specified Nth response is constant from reinforcement to reinforcement (Skinner, 1938). In variable ratio (VR) schedules, the Nth response varies about a specified average N, with the distribution of number of responses specified in advance (Ferster & Skinner, 1957).

Potentially, each kind of schedule differentially reinforces different response rates. On ratio schedules, the rate of responding directly affects the rate of reinforcement, i.e., fast responding brings reinforcement sooner than slow responding. On interval schedules, however, the rate of reinforcement is independent of the rate of responding (provided, of course, that at least one response is made per interval), since responses made before the specified interval has elapsed do not affect the scheduled time of reinforcer availability for the next response.

Because of these differential relations between behavior and reinforcement, it is generally believed that "The effects of each type of schedule are systematic and orderly . . . The particular performance generated depends on the schedule used, but each schedule has characteristic effects" (Zeiler, 1977, p. 201). That such characteristic performances are not a necessary outcome had long since been demonstrated in experiments with interval schedules involving "limited hold" (Clark, 1959; Ferster & Skinner, 1957; Hearst, 1958; Schoenfeld & Cumming, 1957; Schoenfeld, Cumming, & Hearst, 1956), or interval schedules that involve extended training when the interval is long (Cumming & Schoenfeld, 1958); in these experiments, "ratio-like" behavior was observed, although only a single response was required for reinforcement. But because interreinforcement time is free to vary on ratio schedules but not on interval schedules, and because the measure of responses-per-reinforcer is free to vary on interval schedules but not on ratio schedules, attributing performance differences to the kind of schedule would seem to be appropriate only if the schedules are comparable in terms of the measure that is free to vary.

Skinner (1938) had shown that changes in the time between reinforcers on interval schedules affects the rate of responding: increases in the time between reinforcers lowers response rate, and decreases in the time between reinforcers increases response rate. Since an increase in

response rate under a ratio schedule increases the rate of reinforcement, any subsequent increase in response rate may be due either to the ratio contingency or to the decrease in interreinforcement time. One mode of eliminating such confounding was to use the yoked-box experiment of Ferster and Skinner (1957). In their procedure, a subject in one experimental chamber was exposed to a VR schedule. When that subject completed the ratio and was reinforced, a reinforcement was set up in another experimental chamber, which was delivered to a second subject after its next response. Since the second subject did not have to make any particular number of responses before the reinforcer was set up, the subject was effectively on an interval schedule (see also Catania, Matthews, Silverman, & Yohalem, 1977; Killeen, 1969). Yoking may be arranged in the other direction: the first subject is placed on an interval schedule and the number of responses emitted for each reinforcement is counted; the distribution of number of responses-per-reinforcer then becomes the requirements for reinforcement for a second subject in the yoked experimental chamber; the second subject is effectively on a ratio schedule (Catania et al. 1977). Regardless of the direction of yoking, the ratio subject typically responds at a higher rate than the interval subject (Catania et al. 1977; Ferster & Skinner, 1957; Killeen, 1969). Since the two schedules are equated in terms of either the distribution of interreinforcement times or the distribution of number of

responses-per-reinforcer, the higher response rate in the ratio subject is more confidently attributed to the ratio contingency per se. Although the yoked-box method eliminates some of the confounding by equating the schedules in terms of one of the distributions, it is not operationally possible to simultaneously equate interval and ratio schedules in terms of both kind of distributions.

The first attempt to make a ratio schedule comparable to an interval schedule was that described by Skinner (1938), and utilized his concept of an "extinction ratio", which is computed to be the average ratio of unreinforced to reinforced responses produced after training on a fixed interval schedule. The subjects (rats) were trained on an FI schedule, and then switched to an FR schedule, where the response requirement equalled the extinction ratio. Although one of the four subjects accelerated its response rate in the first session, three other rats remained at their FI rates for the first three sessions on FR, and then accelerated in the fourth session (pp. 282-286). This approach, however, does not really make the schedules comparable, since the FI and FR schedules differed in several ways: (a) the distribution of the number of responses-per-reinforcer was variable in FI, and fixed in FR; (b) the schedules differed in terms of the distributions of interreinforcement times; and, (c) the schedules were presented in isolation, which means that the subject had a history of responding under the FI schedule before being

exposed to the FR schedule; however, instances of behavioral "inelasticity" following exposure to some schedules have been reported (Cf. Schoenfeld & Cumming, 1957).

Nonetheless, this method of trying to make interval and ratio schedules comparable for a single subject (by taking the average of some dependent variable under one schedule, and using it as the independent variable for later training under another schedule) is still in use (cf. Capehart, Eckerman, Guilkey, and Shull, 1980).

In a different approach to making interval and ratio schedules comparable for a single subject, pigeons were first trained on a VI schedule. The subjects then were switched to a VR schedule, where the distribution of the number of responses-per-reinforcer was the same as that produced by the animal under the preceding VI schedule (these were the birds that served as the VR subjects in Ferster and Skinner's yoked-box experiment). Here, the VI and VR schedules were more comparable than the FI and FR schedules used by Skinner (1938) in his extinction ratio experiment, because the Ferster and Skinner method equated the schedules in terms of the distribution of the number of responses-per-reinforcer. Nonetheless, the schedules still differed in terms of the distribution of interreinforcement times, and each schedule still was presented in isolation.

Exploring the differences between interval and ratio schedules has not gone beyond the Ferster and Skinner (1957) method of equating VI and VR schedules, in terms of the

distribution of number of responses-per-reinforcer. And yet, any description of such schedules is incomplete without the knowledge of how the limiting case of equated schedules affects behavior of the single subject. Exploration of the effects of the limiting case was the purpose of the present study. The "limiting case" is that in which the interval and ratio schedules are not only equated in terms of some variable (e.g., interreinforcement time or number of responses-per-reinforcer), but also are presented to the subject as near to simultaneously as possible; the latter requirement eliminates the influence of an earlier history under one schedule, before exposure to the other schedule. The limiting case is arrived at by way of Skinner's extinction ratio; it differs from Skinner's procedure in that the extinction ratio is computed after each reinforcement on FI, rather than after training on FI in isolation. The procedure operates as follows: a subject on an FI schedule emits a total of, say, 20 responses, the last of which is reinforced; after the FI reinforcement is delivered, the schedule immediately changes to a ratio schedule, in which the 20 responses just produced in the FI schedule now becomes the response number requirement for reinforcement; when the 20th response is produced in the ratio schedule, and is reinforced, the FI schedule is again in effect. This cycle, consisting of an FI schedule, in effect for a single reinforcement, followed by a ratio schedule, based on the number of responses in the

just-completed FI schedule, is continuously repeated. In such a case, the ratio schedule is yoked to the FI schedule, with the schedule changing after every reinforcement, in simple alternation. Here, the FI and ratio schedules are equated in terms of the number of responses-per-reinforcer, as they were in Ferster and Skinner's yoked-box experiment, but they are separated from each other by no more than a single reinforcement. Such schedules may be called "self-yoked," to distinguish the procedure from those which yoke one subject to another. In such a procedure, a ratio contingency is put to the ultimate test; its "special nature" (Skinner, 1938, p. 286), if such exists, will produce behavior that is different from an interval schedule, under conditions where the two kinds of schedules are most comparable.

The self-yoked procedure was used in the two experiments that constitute the present study. Experiment I explored the effects of the basic self-yoked procedure. Experiment II investigated the effects of adding a correlated exteroceptive stimulus to one of the schedules in the self-yoked procedure.

Method

Subjects

Five naive male, white Carneaux pigeons, approx. 6-8 years old at the beginning of the study, served as subjects in both experiments. The birds were maintained at approximately 80% of their free-feeding weights.

Apparatus

The experimental chamber was a three-key Lehigh Valley Electronics pigeon chamber, Model 1519C. Only the center key was used. A peck having a force of approx. 0.2 Newton closed a microswitch located behind and attached to the key. The feeder was illuminated during reinforcement, which consisted of approx. 2.5 sec access to mixed grain. The schedules and the delivery of reinforcement were controlled by solid-state digital logic devices.

Procedure

Experiment I. Each subject was manually shaped to peck the center key, which was dark. Following shaping, 100 regular (crf) reinforcements were given. The first experimental condition began on the next day.

Each experimental condition consisted of alternating FI and yoked-ratio (YR) schedules, with schedule changes taking place after each reinforcement; thus, the schedules were components of a mixed schedule (Ferster & Skinner, 1957). The FI schedule was timed from the end of the preceding reinforcement. Only the FI value was fully specified; the

YR requirements were determined by the animal's behavior in each preceding FI component, as follows: the number of responses emitted in an FI component served as the requirement for reinforcement in the immediately following YR component. For example, if the subject made 20 responses in an FI component, then 20 responses were required for reinforcement in the immediately following YR component. Four values of FI were used: 15, 30, 60, and 120 sec. The first value of FI to be used was 15 sec. When behavior at an FI value was stable for five sessions, based on inspection of the cumulative records and quantitative session data, the FI value was changed; a minimum of 20 sessions was run at each FI value. The FI values were increased in ascending order. The final condition of Exp. I was reexposure to FI 15. Sessions began with reinforcement for the first response. Sessions ended following 50 additional reinforcements at FI 15, 40 additional reinforcements at FI 30, and 30 additional reinforcements at FI 60 and FI 120. The procedure was identical for all subjects. Table 1 summarizes the conditions, and shows the number of sessions each was in effect.

Experiment II. The schedule parameters used in Exp. II were identical to those used in Exp. I. In Exp II, multiple schedules were also used. The multiple schedules were created by the addition of an exteroceptive stimulus (key light) to one of the components of the self-yoked schedule. The experiment thus consisted of both mixed and multiple

Table 1

Summary of experimental conditions in Exp. I, and the number of sessions each was in effect. The sequence of conditions was from top to bottom of the table.

FI value (sec)	Schedule	Sessions
15	Mixed	30
30	Mixed	20
60	Mixed	20
120	Mixed	20
15	Mixed	20

schedule conditions; however, only one of these conditions (either a mixed or a multiple schedule) was in effect at any one time.

Within each value of FI, there was a sequence of five conditions, as follows: (1) mixed schedule (key light off in both components), (2) multiple schedule (key light on during either FI or YR), (3) mixed schedule (key light on during both components), (4) multiple schedule (same as condition 2), and (5) mixed schedule (same as condition 1). Stability criteria were the same as in Exp. I. When behavior was stable, a condition was changed: for example, condition 1 (a mixed schedule) was changed to condition 2 (a multiple schedule). The sequence of five conditions was repeated for each value of FI. The FI value was increased in ascending order. The procedure was identical for all subjects, except that in the multiple schedules, the key light was on in FI for Birds 35, 38, and 39, and was on in YR for Birds 33 and 37. Table 2 summarizes the conditions, and gives the number of sessions that each was in effect.

Table 2

Summary of experimental conditions in Exp. II, and the number of sessions each was in effect. The sequence of conditions was from top to bottom of the table.

FI value (sec)	Condition number	Schedule	Sessions
15	1	Mixed	6*
15	2	Multiple	20
15	3	Mixed	20
15	4	Multiple	20
15	5	Mixed	15
30	1	Mixed	20
30	2	Multiple	25
30	3	Mixed	20**
30	4	Multiple	15
30	5	Mixed	10
60	1	Mixed	20
60	2	Multiple	25
60	3	Mixed	20
60	4	Multiple	15
60	5	Mixed	15
120	1	Mixed	20

120	2	Multiple	30
120	3	Mixed	20
120	4	Multiple	15
120	5	Mixed	15

*These sessions were preceded by 20 identical sessions in Exp. I. Fourteen days intervened between Exp. I and Exp. II, during which subjects were maintained at 80% of their free-feeding weights.

**Bird 37 expired after completing 18 sessions.

Results

Four response measures constitute the data of the experiments: (1) post-reinforcement pause (PS^{RP}), (2) corrected rate (also called "rate"), and computed by dividing the number of responses-per-reinforcer by the interreinforcement time, after the duration of reinforcement time is subtracted, (3) running rate, computed by dividing the number of responses-per-reinforcer by the interreinforcement time, after both the duration of reinforcement time and the PS^{RP} are subtracted, and (4) number of responses-per-reinforcer. For individual subjects, response measures are means of the median value of each of the last five sessions of a condition. For the group data, measures are means of the mean values of the individual subjects.

Experiment I

Figure 1 shows that rates were essentially the same in FI and YR. The non-differential rates were observed in all subjects, and at all values of FI, including recovery at FI 15. For three subjects (Birds 33, 35, and 37), recovered rates at FI 15 were virtually identical to those in the initial exposure to the condition; for two subjects (Birds 38 and 39), recovered rates were slightly lower than during the first exposure to the condition. The figure also shows that rate was generally a flat function of increasing FI value; the exception was Bird 39, whose rate decreased with increases in intermittency of reinforcement.

Figure 1. Corrected rates of each bird in Exp. I, as a function of FI value.

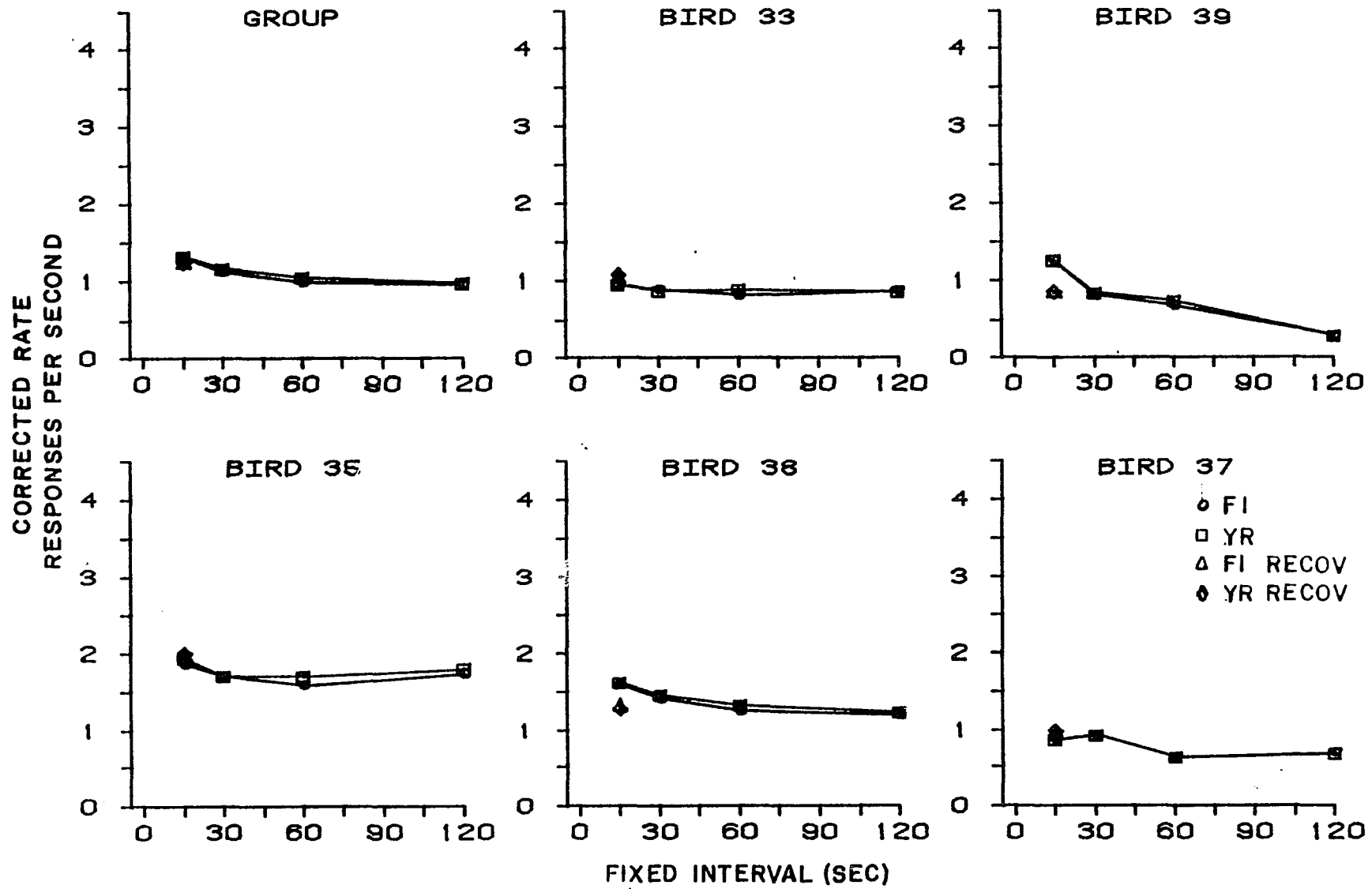


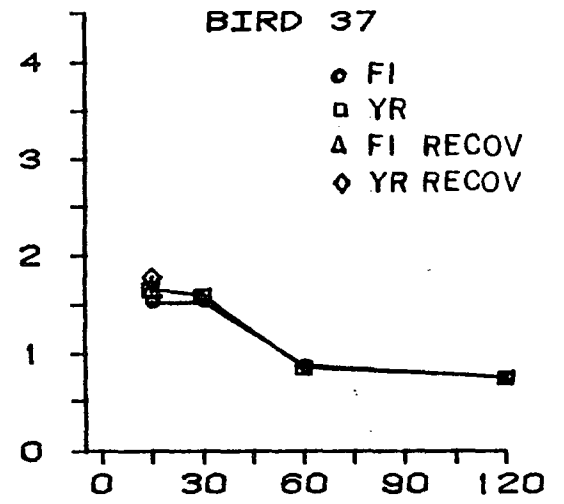
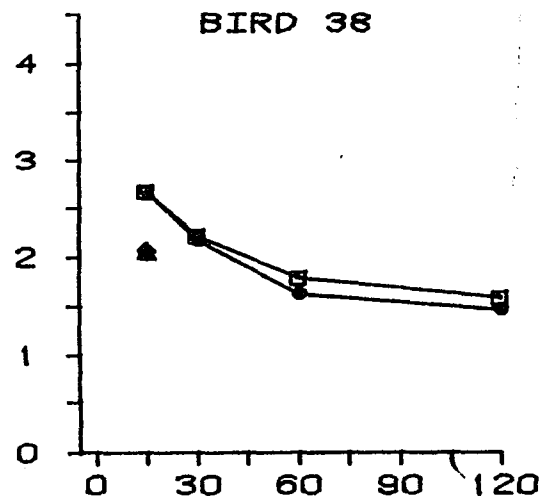
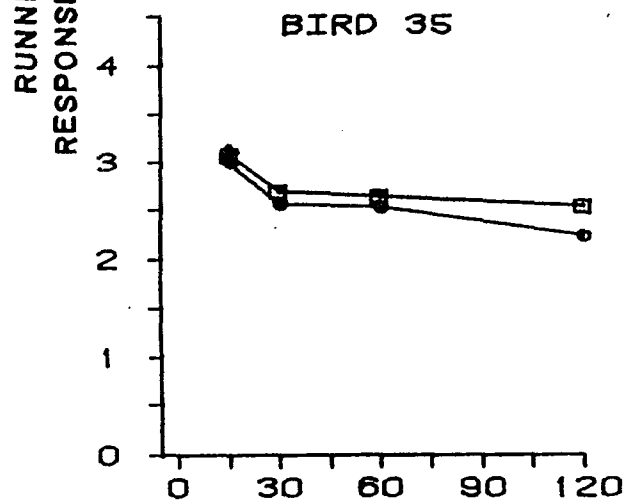
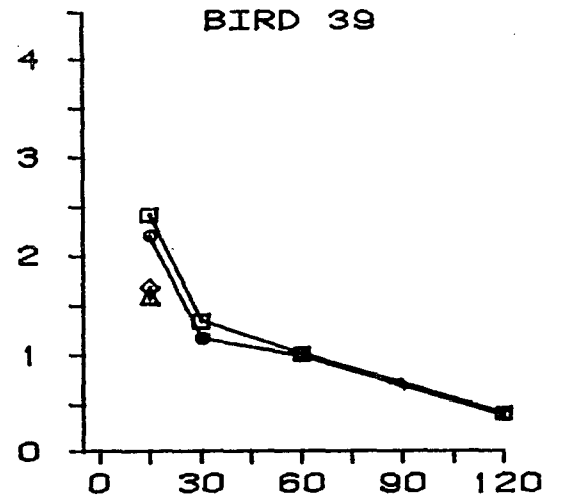
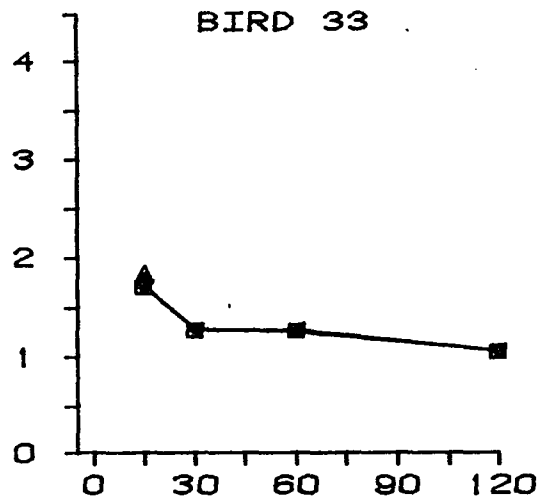
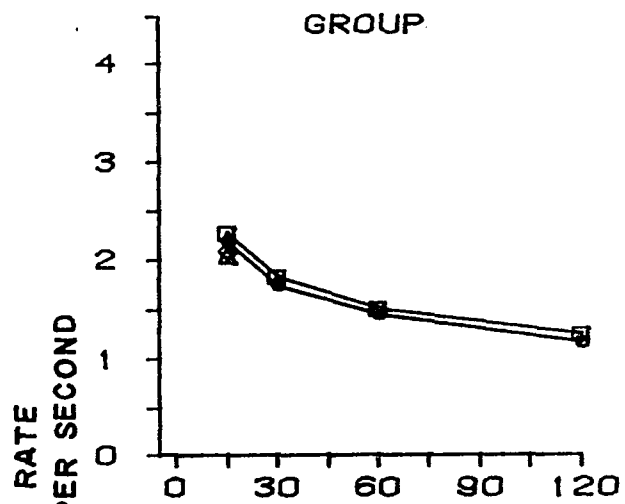
Figure 2 shows that, as with corrected rate (see Figure 1), running rate was non-differential in FI and YR. Also, as seen with corrected rate, Birds 38 and 39 showed lower running rates on reexposure to FI 15. Unlike corrected rate, however, running rate was a decreasing function of increasing FI value.

Figure 3 shows that, as with corrected rate and running rate, the post-reinforcement pause (PS^{RP}) was generally the same in FI and YR. The PS^{RP} in the reexposure to FI 15 was virtually identical to that in the initial exposure to the same condition. The PS^{RP} was generally a monotonic, increasing function of FI value, except for Bird 37, whose pause decreased at FI 120, from that at FI 60.

Responses-per-reinforcer data are plotted in Figure 4. Because FI and YR were equated on this measure, the functions for FI and YR overlap. The figure shows that the number of responses-per-reinforcer was an increasing, linear function of FI value, except for Bird 39, whose response output leveled off at FI 60.

Partial cumulative records for each bird, taken from the final session at each value of FI, are shown in Figure 5. Because of the similarity of behavior in FI and YR, it is difficult to determine which of the schedule components was in effect. More easily seen are those occasions when the subject paused for the entire (or almost the entire) duration of the FI component, and thus emitted very few responses ("a"); such instances were typically followed by a

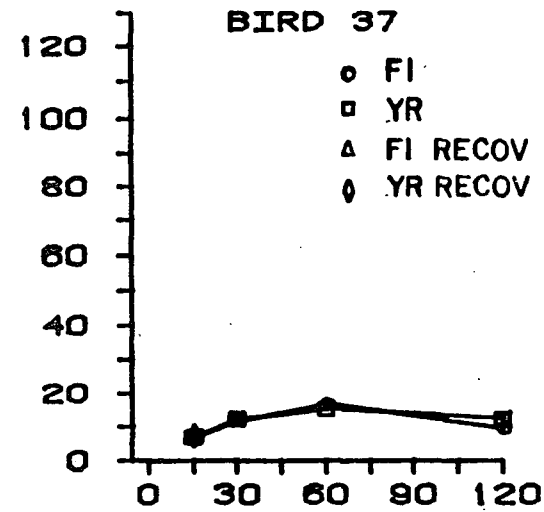
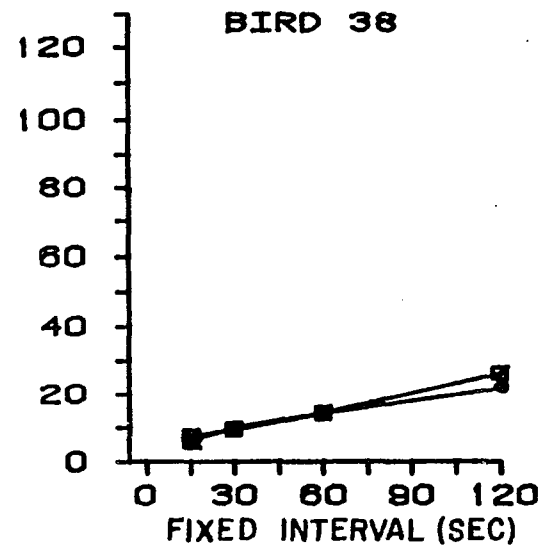
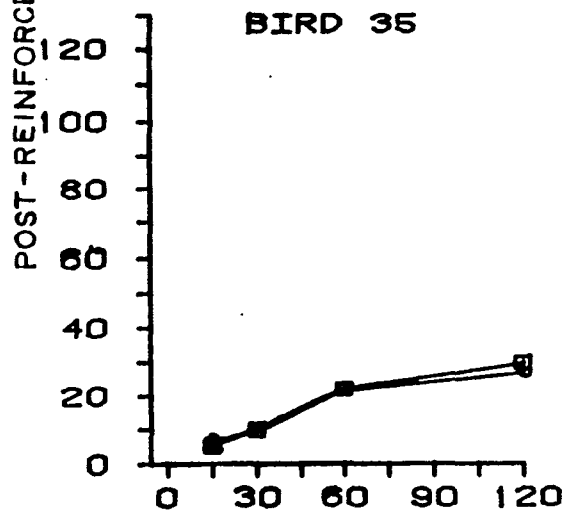
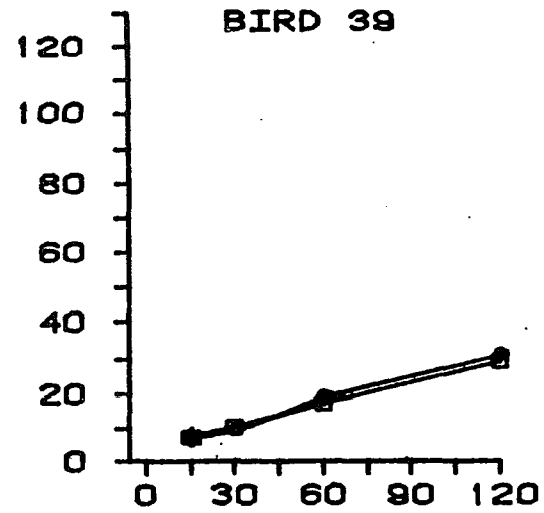
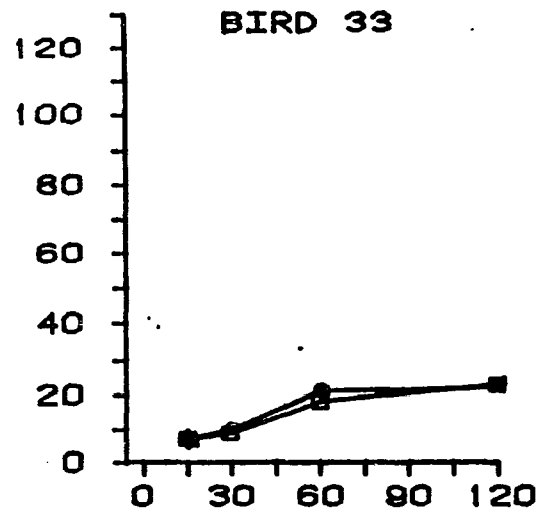
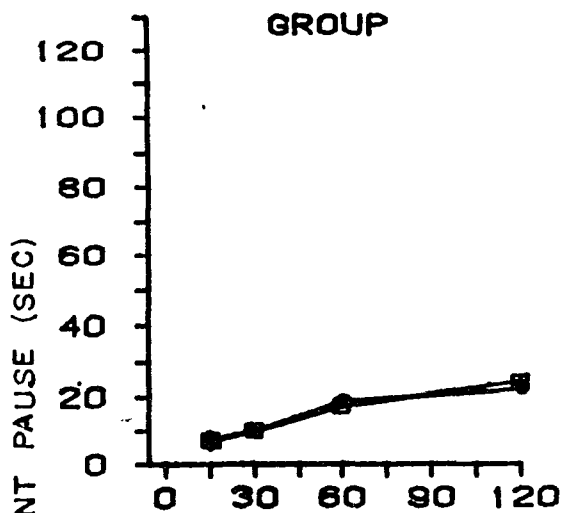
Figure 2. Running rates of each bird in Exp. I, as a function of FI value.



FIXED INTERVAL (SEC)

- FI
- YR
- △ FI RECOV
- ◇ YR RECOV

Figure 3. Post-reinforcement pauses of each bird in Exp. I, as a function of FI value.



- FI
- YR
- △ FI RECOV
- ◇ YR RECOV

Figure 4. Responses-per-reinforcer of each bird in Exp. I, as a function of FI value.

Since this is the measure on which the FI and YR components were equated, the functions overlap.

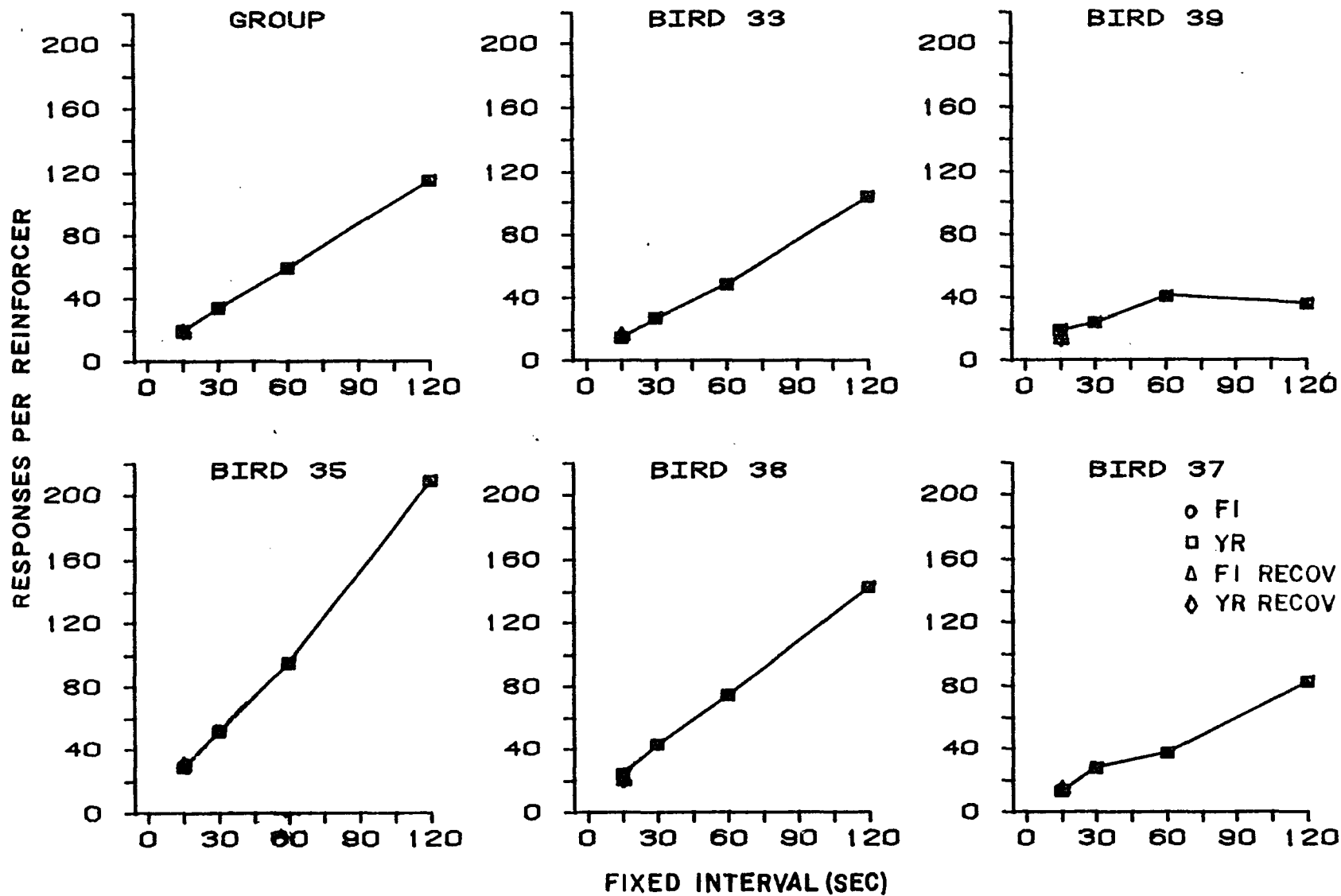
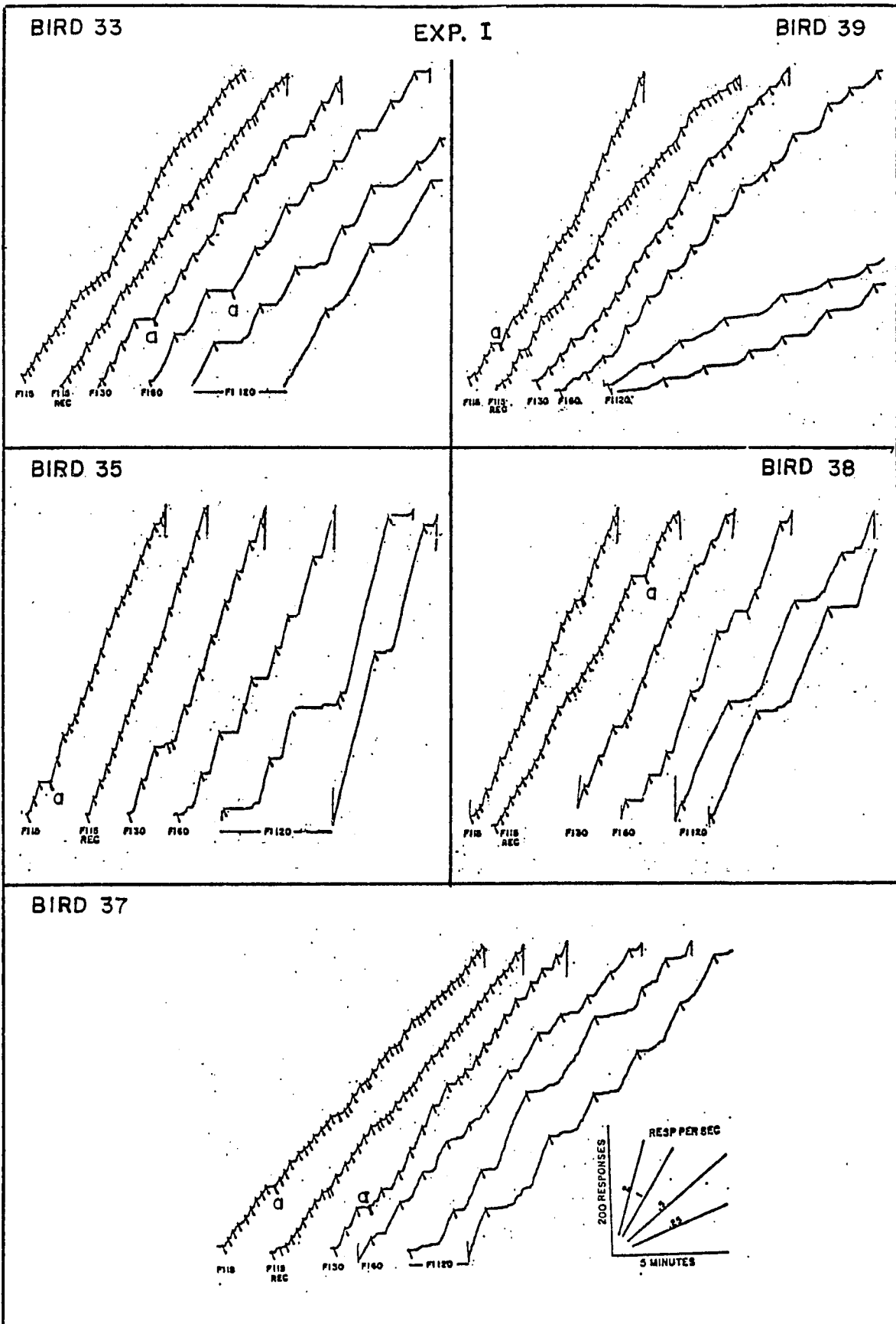


Figure 5. Partial cumulative records of each bird in Exp. I.

The records were taken from the final session at each value of FI. The letter "a" indicates instances where the subject paused for the entire (or almost the entire) duration of the FI component (see text).



very short PS^{RP} (approx. one or two sec), so that reinforcement in YR came quickly; the PS^{RP} in the next FI component usually was equally short, and was followed by a steady run of responding until interrupted by reinforcement, and which thus resulted in a higher than average number of responses-per-reinforcer; higher than average response outputs were inevitably followed by increases in PS^{RP} ; bringing response rates and pauses back to their average values. These instances of "a" were infrequent, occurring mostly at the lower FI values, and almost never at FI 120; most oscillations in response rates and pauses were closer to the averages. Recovered performance at FI 15 is virtually indistinguishable from that during initial exposure to the same value, except for the slightly lower rate of Bird 39.

At FI 15 and FI 30, the pattern of responding in both FI and YR was basically "break-run" for all birds, which is typical at short values of FI (cf. Schneider, 1969; Sherman, 1959). At FI 60, break-run behavior continued in Bird 35; Birds 33, 37, and 38 also showed mostly break-run behavior, but with occasional instances of slower transition from PS^{RP} to terminal response rate; Bird 39 showed "scalloping" in both FI and YR. At FI 120, all subjects (except Bird 39) showed behavior that was more scalloped, although the responding was irregular, with additional pauses between some reinforcers; as at FI 60, Bird 39 showed scalloped behavior in both FI and YR. Although break-run

behavior may be typical at short FI values, scalloped behavior under ratio schedules has not been previously reported.

The results of Experiment I may be summarized, as follows: behavior of all subjects was essentially the same in both FI and YR, in all of the responses measures that were taken, at all values of FI, including recovery at FI 15.

Experiment II

In Exp. I, subjects were exposed to only one condition at each value of FI: a mixed schedule (see Table 1). In Exp. II, subjects were exposed to five conditions at each FI value (see Table 2). Thus, data at each value of FI are plotted in the Figures as two sequences of five conditions each: one sequence is for FI components (circles); the other sequence is for YR components (squares). Since responses-per-reinforcer was the measure on which FI and YR were equated, only one sequence is necessary.

Four FI values were used, and thus there are four pairs of sequences. The first, third, and fifth data points of a sequence are for mixed schedules; the second and fourth data points are for multiple schedules. The five data points within a sequence are connected, but the sequences themselves are not connected, in order to demarcate differences in FI values. In the text, the multiple and mixed schedules are identified as "conditions," which correspond to the above data point numbers, i.e., conditions

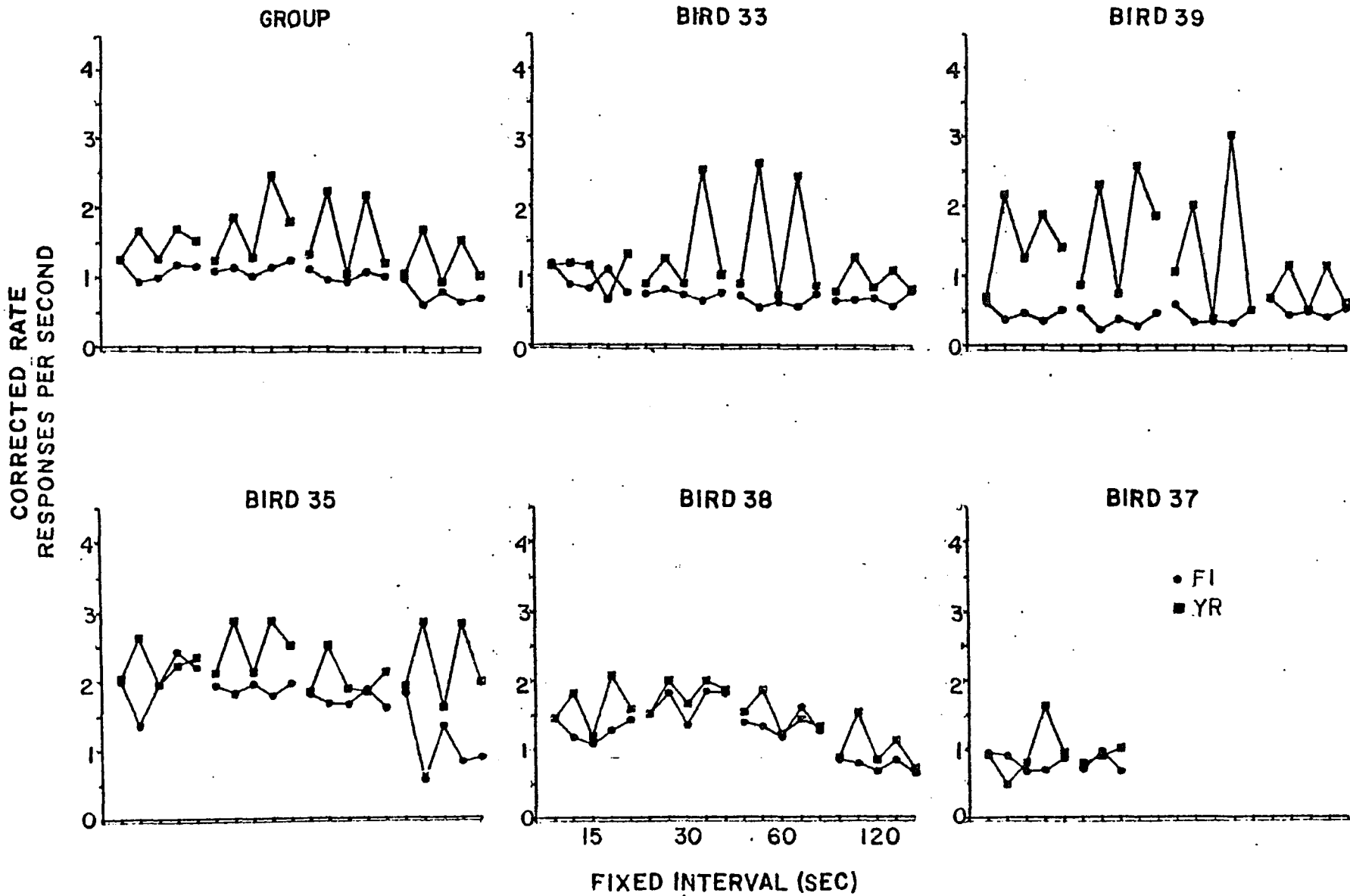
1, 3, and 5 represent mixed schedules, and conditions 2 and 4 represent multiple schedules. Also in the text, the simple abbreviations "FI" and "YR" refer to components of the mixed and multiple schedules; the phrases "FI value" or "value of FI" refer to the independent variable, i.e., FI 15, FI 30, FI 60, and FI 120 sec. One subject (Bird 37) expired after completing 18 sessions of condition 3 at FI 30 (see Table 2).

Figure 6 shows that the addition of a correlated cue in the multiple schedules (conditions 2 and 4, at each FI value) generally, but not always, resulted in the separation of FI and YR rates. The magnitude of the differences in rates was not systematically related to the FI value, and the effect ranged from very small (Bird 35, in condition 4 of FI 15 and FI 60; Bird 38, in conditions 2 and 4 of FI 30, and in condition 4 of FI 60; Bird 37, in condition 2 of FI 30) to very large (Bird 33, in condition 4 of FI 30, and in conditions 2 and 4 of FI 60; Bird 39, in conditions 2 and 4 of FI 15, FI 30, and FI 60; Bird 35, in condition 2 of FI 15, and in conditions 2 and 4 of FI 120). Rates in condition 3 (key light on in both FI and YR) were not systematically different from those in conditions 1 and 5 (key light off in both FI and YR).

In some instances rates in YR were actually lower than in FI. For example, Bird 37's rate was lower in YR than in FI during the first exposure to the multiple schedule (condition 2 of FI 15), but in the second exposure to the

Figure 6. Corrected rates of each bird in Exp. II.

There are four sequences of five conditions each. Each sequence is for one value of FI, as indicated below the center graph in the lower row. The five data points (conditions) of each sequence are connected; the sequences are separated to demarcate differences in FI value. The first, third, and fifth data points of a sequence are mixed schedules; the second and fourth data points are multiple schedules. Bird 37 expired after completing condition 3 of FI 30.



same condition (condition 4 of FI 15) the bird reversed its relative rates, so that rate in YR was higher than in FI. A reversal in relative FI and YR rates was also observed in Bird 33: the subject responded at a higher rate in YR during first exposure to the multiple schedule (condition 2 of FI 15), but responded at a lower rate in YR than in FI in the second exposure to the same condition (condition 4 of FI 15). Ferster and Skinner (1957) had suggested that inadequate training on VI was the reason that responding extinguished in one of their birds when switched to VR in their yoked-boxes experiment (pp. 405-406). Since the reversal by Bird 33 in the present experiment occurred in the second exposure to the same condition, the lower rate in YR by Bird 37 during first exposure to the multiple schedule was not necessarily the result of inadequate training; more likely, the uncertainty of the direction of rate change in YR is due to some property of the self-yoked procedure.

Although the data show that both of the above reversals occurred at the lowest FI value (FI 15), there were two other instances of lower rates in YR than in FI, both of which occurred during the first exposure to the longest FI value (FI 120). One of the reversals also involved Bird 33; the other subject was Bird 38. These subjects progressively lowered their rates in YR, so that by session 13 of condition 2 at FI 120 (a multiple schedule) responding had stopped. Ferster and Skinner's bird stopped responding with a ratio requirement of 1980 responses; in comparison, Bird

33's responding extinguished during a YR requirement of 165 responses, and Bird 38's responding stopped during a YR requirement of 155 responses. Extinction in Bird 33 occurred while the YR component was correlated with a dark key, and Bird 38 while the YR component was correlated with a lighted key. Responding in YR was immediately restored in both subjects by reversing the key light correlation, which meant that the stimulus controlling slow responding then was correlated with FI; as the data show, extinction in YR did not recur.

Some subjects showed some, although reduced, separation of FI and YR rates after removal of the correlated cue, at least up to the point when the experimental condition was changed. The effect is most dramatically seen in Bird 39: much higher rates in YR than in FI were observed in conditions 3 and 5 of FI 15, and in condition 5 of FI 30; in condition 1 of FI 30 and FI 60, there was some transfer of the differential responding when the FI value was increased; in later mixed schedules, behavior was once again non-differential in the mixed schedules. Bird 35 showed differences in FI and YR rates in condition 5 of FI 30, and in condition 5 of FI 120; interestingly, the subject responded at a higher rate in YR than in FI in condition 5 of FI 60 (a mixed schedule), after non-differential responding in condition 4 (a multiple schedule). A similar result was reported by Ferster and Skinner (1957), in which rats trained on a multiple schedule (FR 20 FI 5 min), in

which the components changed after each reinforcement (alternated), were then switched to the same schedule without the differential stimuli, i.e., they were placed on a corresponding mixed schedule. Some disruption of behavior occurred for a few reinforcements, but "all 3 rats very quickly developed an essentially multiple schedule performance on the mixed schedule" (p. 625). The schedule components were, however, very different from one another, in terms of the minimum possible time between reinforcers under each schedule, and which thus may have been the basis of a temporal discrimination. In the present experiment, the schedules were very similar (equated), which may account for the reduction in differential responding when the correlated cue was removed. It is not known whether Ferster and Skinner's rats would have shown "alternation" behavior in the mixed schedule without their history under the corresponding multiple schedule.

Figure 6 also shows that the presence of the correlated cue (in the multiple schedules) did not affect rates in YR and FI equally. Rather, there were large increases in YR rates, but small changes, if any, in FI rates. Bird 35 showed a few symmetrical changes in FI and YR rates in condition 2 of FI 15 and in conditions 2 and 4 of FI 120, i.e., FI rates decreased about as much as YR rates increased; although the rate of reinforcement in YR was not directly manipulated in the present experiment, the change in response rate in FI bears some resemblance to what has

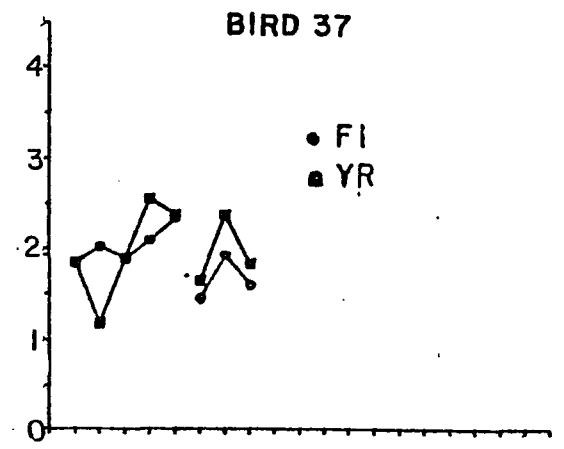
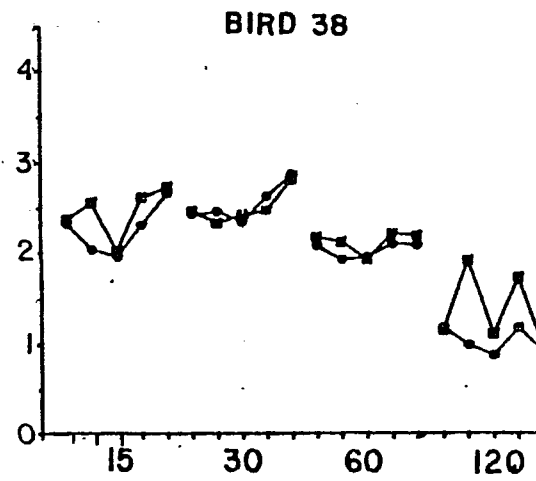
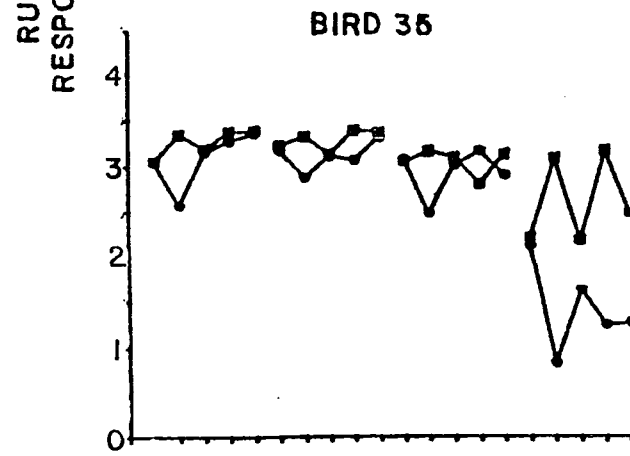
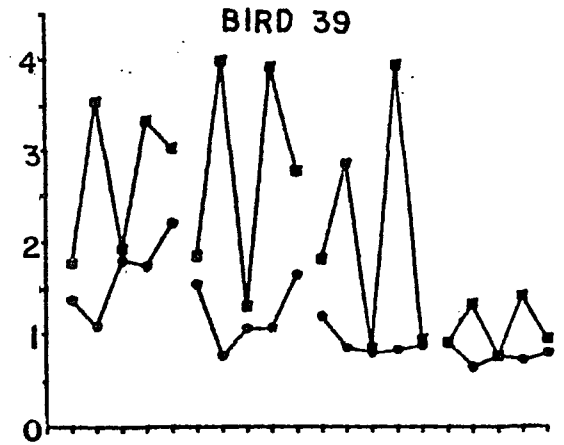
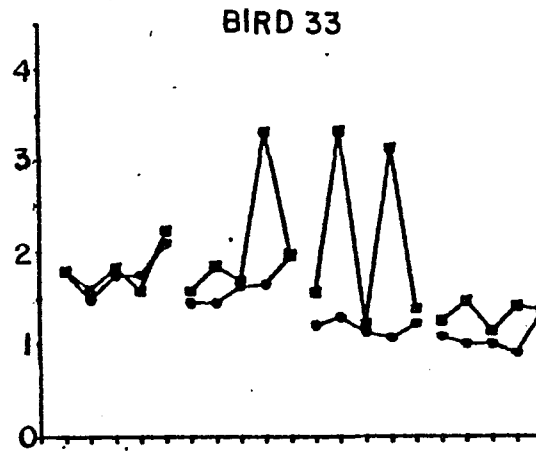
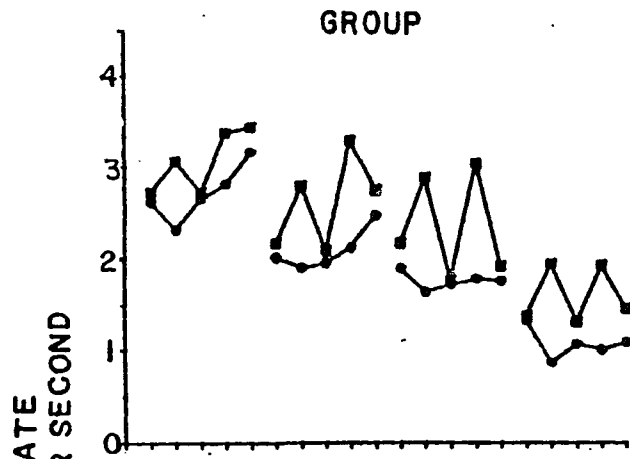
been labeled "behavioral contrast" (Reynolds, 1961a,b,c). Bird 39 showed only a small decrease in FI rates in conditions 2 and 4 of both FI 15 and FI 30, whereas YR rates increased greatly. In general, however, FI rates in the multiple schedules changed little from those in the mixed schedules, and where changes did occur, they usually were not systematic.

Figure 6 also shows that average rates in FI decreased only slightly as FI value was increased, a result also observed in Exp. I (see Figure 1). Bird 39 showed almost no change in average FI rate with increases in intermittency of reinforcement; in Exp. I, the bird's rate was lower at FI 120 than at the other FI values. Bird 35 showed a decrease in average rate in FI only at FI 120. Bird 38 increased its rate in FI at FI 30, but rate declined at FI 60, and again at FI 120; in Exp. I, rates declined slightly, but monotonically, with increases in FI value (see Figure 1). Bird 33's average rate in FI declined very slightly from FI 15 to FI 60, but not at FI 120; in Exp. I, the rate did not change with increases in intermittency of reinforcement (see Figure 1). The differences between corrected rates in the two experiments are attributed to the presence of the multiple schedules in Exp. II.

The contributions of running rate and post-reinforcement pause (PS^{RP}) to corrected rate are presented in Figures 7 and 8, respectively. In general, the differences in corrected rates that were observed between the mixed and

Figure 7. Running rates of each bird in Exp. II.

There are four sequences of five conditions each. Each sequence is for one value of FI, as indicated below the center graph in the lower row. The five data points (conditions) of each sequence are connected; the sequences are separated to demarcate differences in FI value. The first, third, and fifth data points of a sequence are mixed schedules; the second and fourth data points are multiple schedules. Bird 37 expired after completing condition 3 of FI 30.

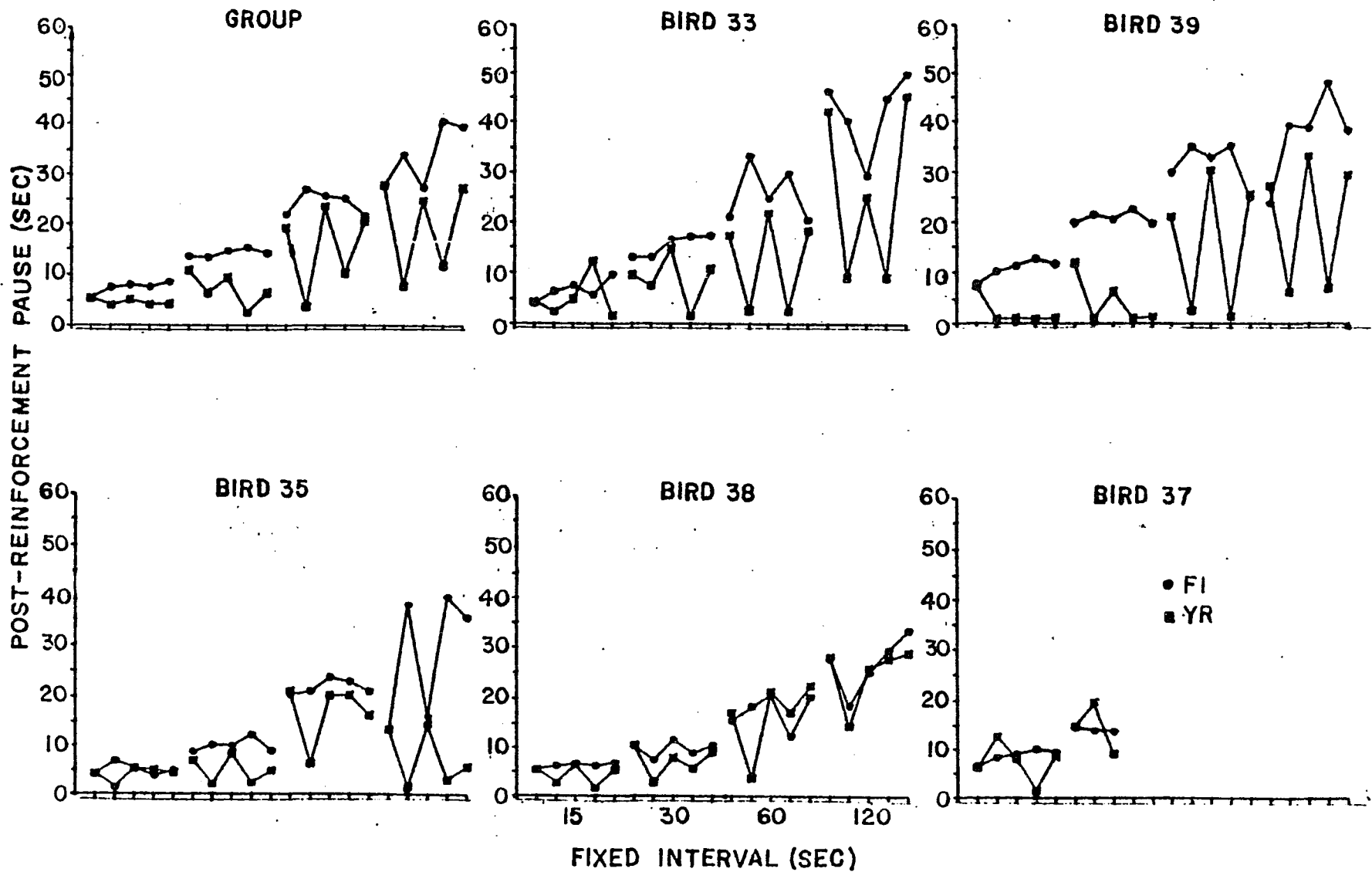


● FI
■ YR

FIXED INTERVAL (SEC)

Figure 8. Post-reinforcement pauses of each bird in Exp. II.

There are four sequences of five conditions each. Each sequence is for one value of FI, as indicated below the center graph in the lower row. The five data points (conditions) of each sequence are connected; the sequences are separated to demarcate differences in FI value. The first, third, and fifth data points of a sequence are mixed schedules; the second and fourth data points are multiple schedules. Bird 37 expired after completing condition 3 of FI 30.



multiple schedules (see Figure 6) were also observed in running rates, i.e., running rates were more separated in FI and YR under the multiple schedules than under the mixed schedules.

Across the five conditions of an FI value, the data show that, for three subjects (Birds 33, 39, and 37) the range of running rates in FI was greater than the range of corrected rates in FI (see Figure 6). Bird 39 showed the greatest range of FI running rates at FI 15 and FI 30, but the ranges at FI 60 and FI 120 were similar to ranges in corrected rates. For Bird 35, the range of running rates in FI was about the same as for corrected rates. With Bird 38, running rates in FI at FI 60 occupied a smaller range than did corrected rates. Although there was little decrease in corrected rates in FI as value of FI increased (see Figure 6), running rates in FI declined more substantially with increases in intermittency of reinforcement; the single exception to this trend was seen in Bird 38 at FI 15, where the average running rate in FI was lower than at FI 30.

Figure 8 shows that the greater separation of corrected rates and running rates under the multiple schedules than under the mixed schedules was also seen in post-reinforcement pause. The differences between PS^{RPs} in FI and YR under the multiple schedules were manifested by large reductions in YR, but small changes in FI at the shorter FI values, and moderate changes in FI at the longer FI values. Across the conditions of an FI value, the range

of PS^{RP} s in FI increased with increases in intermittency of reinforcement; the larger range of PS^{RP} s in FI at the longer FI values is contrasted with the larger range of running rates in FI at the shorter FI values (see Figure 7). Functional independence of running rate and PS^{RP} has previously been reported by Cole (1968); Farmer and Schoenfeld (1967), and Killeen (1969).

Although the group data reflect the general effects of the experimental manipulations on running rate and PS^{RP} , several differences in individual performances were observed at some values of FI. At FI 15, Bird 33's corrected rates in FI and YR were separated in all but condition 1 (see Figure 6); separated running rates were not observed in the same conditions, and thus the differences in corrected rates were produced solely by the differences in PS^{RP} s. (see Figure 8); thus the reversal of relative corrected rates in FI and YR in condition 4 (see Figure 6) was also due solely to a reversal in the relative PS^{RP} s. With Bird 39, the differences between corrected rates in FI and YR in condition 3 of FI 15 (see Figure 6) were not seen between FI and YR running rates; the difference in corrected rates in that condition thus was the result of differences in PS^{RP} ; this subject's PS^{RP} in YR was near zero in all but condition 1 of FI 15, which shows that control over PS^{RP} in YR was about the same in the mixed and multiple schedules, at this value of FI; the tight control over PS^{RP} with and without the correlated cue decreases with

increases in intermittency of reinforcement, but still was considerable at FI 30. With Bird 35, running rate in YR was lower than in FI in condition 4 of FI 60, which normally would produce a lower corrected rate in YR than in FI; that effect, however, was offset by a shorter PS^{RP} in YR than in FI, so that the net result was non-differential corrected rates; the symmetrical changes in FI and YR corrected rates under the multiple schedules of FI 120 were the result of symmetrical changes in both running rate and PS^{RP} . With Bird 38, running rates in FI and YR at FI 30 and FI 60 were close to non-differential in the multiple as well as the mixed schedules; at FI 30, the increased corrected rates under the multiple schedules was not seen in the running rates, which remained virtually flat until condition 5, when the running rates increased in both FI and YR; thus the changes in corrected rates in conditions 2 and 4 of FI 30 were solely the result of shorter PS^{RPs} ; since running rates in FI and YR were about the same in condition 2 of FI 60, the much higher corrected rate in YR in the same condition was the result of the much shorter PS^{RP} in YR than in FI. With Bird 37, the non-differential corrected rates in FI and YR in condition 2 of FI 30 were the result of an increase in the PS^{RP} in YR, which offset the increase in running rate; the higher corrected rate in YR in condition 3 of FI 30 (a mixed schedule) was the result of an increase in running rate and a decrease in PS^{RP} . With the group data, the preservation of differential PS^{RPs}

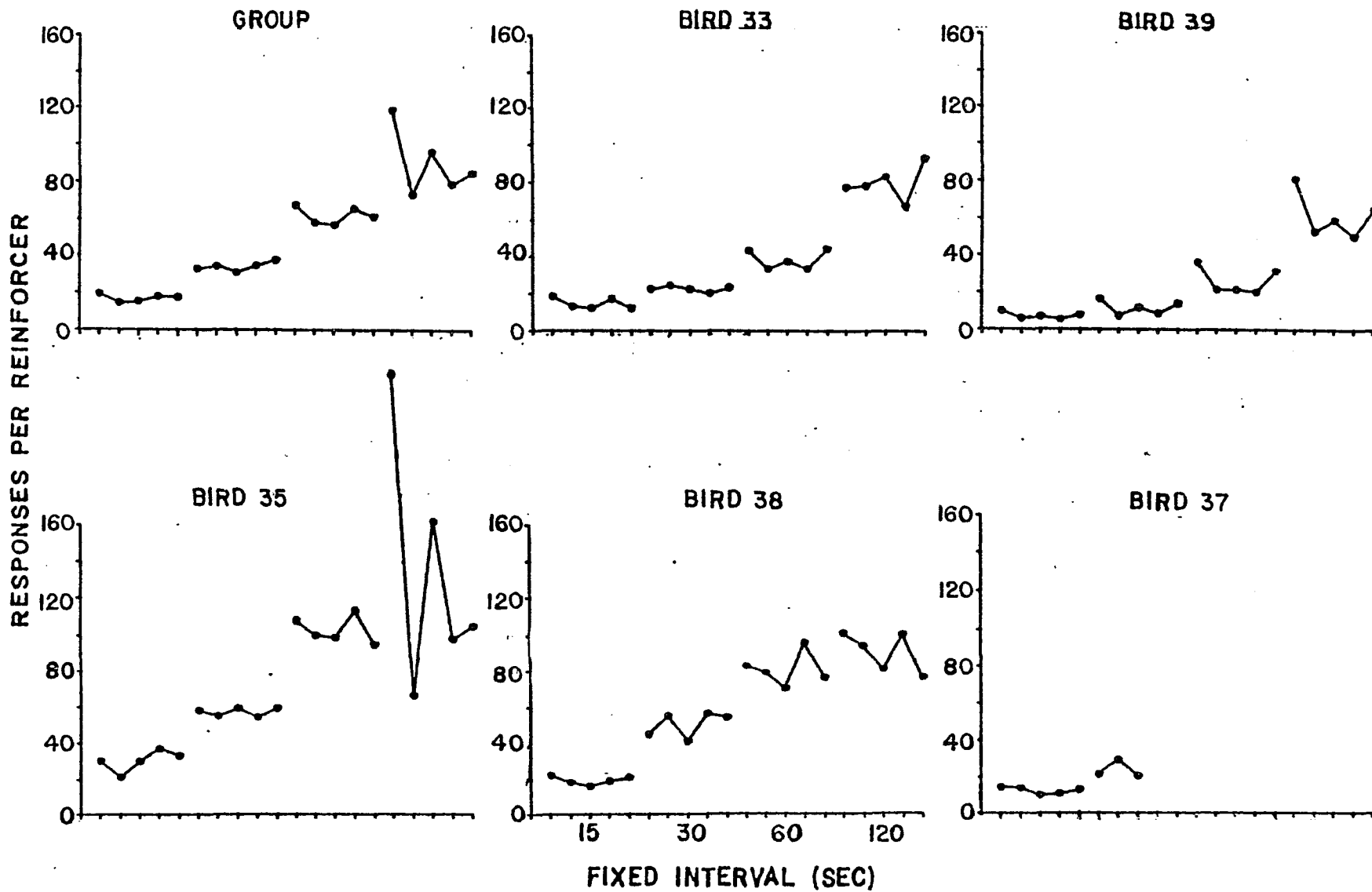
in conditions 3 and 5 of FI 15 was primarily due to Bird 39's near-zero PS^{RP} in YR. The foregoing are further examples of the functional independence of running rate and PS^{RP} .

The data for number of responses-per-reinforcer are shown in Figure 9. Because the number of responses-per-reinforcer in FI and YR were the same (equated), only one curve is shown at each value of FI; thus the circles on the figure represent both FI and YR. Although there were variations within an FI value, the number of responses-per-reinforcer is generally an increasing monotonic function of the FI value. The finding that corrected rate in FI changed very little with increases in FI value (see Figure 6), means that responses-per-reinforcer must have increased as a linear function of increases in intermittency of reinforcement, which, in general, was the case for all subjects.

Also, in general, the range of responses-per-reinforcer within an FI value increased with increases in intermittency of reinforcement, with the largest variation occurring in Bird 35. Since running rates in FI changed very little at the longer FI values (see Figure 7), increases in the number of responses-per-reinforcer at those intermittencies were the result primarily of changes in the PS^{RPs} (see Figure 8). The narrower range in the number of responses-per-reinforcer at the short FI values may be the result of a ceiling effect, since very few responses can be

Figure 9. Responses-per-reinforcer of each bird in Exp. II.

There are four sequences of five conditions each. Each sequence is for one value of FI, as indicated below the center graph in the lower row. The five data points (conditions) of each sequence are connected; the sequences are separated to demarcate differences in FI value. The first, third, and fifth data points of a sequence are mixed schedules; the second and fourth data points are multiple schedules. Since FI and YR were equated on this measure, only one curve is shown for each value of FI. Bird 37 expired after completing condition 3 of FI 30.



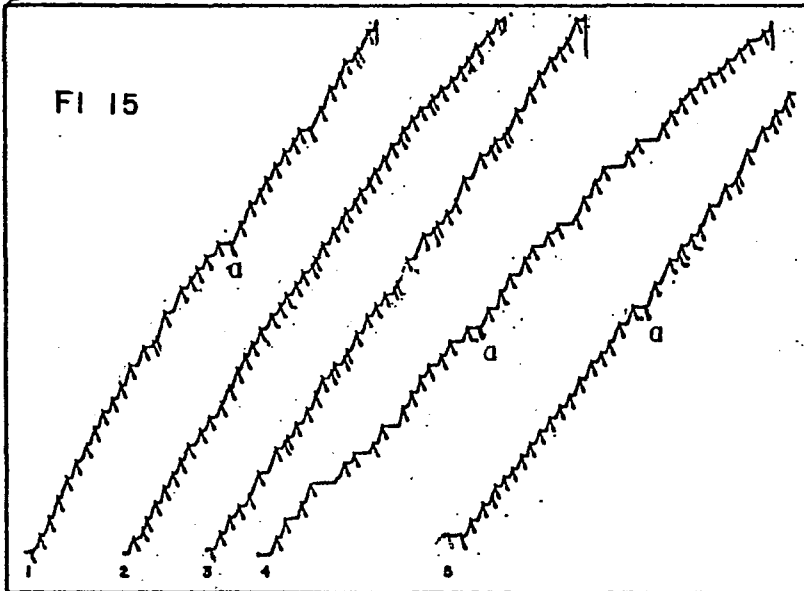
produced in a short interval; at the long FI values, the range of response numbers can be much greater, and thus more variable.

Partial cumulative records for each bird, taken from the final session of each condition, are shown in Figures 10 through 14. In general, the records for the mixed schedules (conditions 1, 3, and 5) resemble those of Exp. I, except for the lower rate in Bird 38 at FI 120; thus, as with the records of Exp. I, it is difficult in most cases to determine which schedule component was in effect. As in Exp. I, there were instances where the subject paused for the entire (or almost the entire) duration of the FI component, and thus emitted very few responses ("a"); the behavior following "a" was the same as that described for Exp. I, above.

The FI and YR components in the multiple schedules (conditions 2 and 4) are easily identified in some birds, but not in others. For example, scalloping in FI, and short PS^RPs in YR that are followed by sustained responding into reinforcement, are typical in Birds 33 and 39 at all FI values; with Bird 35, the patterns are clear only at FI 120; with Birds 38 and 37, such patterns occur infrequently. There were instances of "a" in the multiple schedules in all subjects (Bird 33, in condition 4 of FI 15; Bird 39, in condition 4 of FI 15, and in condition 4 of FI 30; Bird 35, in condition 2 of FI 15, and in condition 2 of FI 120; Bird 38, in condition 2 of FI 15, and in condition 4 of FI 120;

Figure 10. Partial cumulative records of Bird 33 in Exp. II.

The records were taken from the final session of each condition. The letter "a" indicates instances where the subject paused for the entire (or almost the entire) duration of the FI component (see text).



BIRD 33
EXP. II

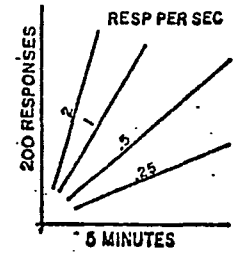
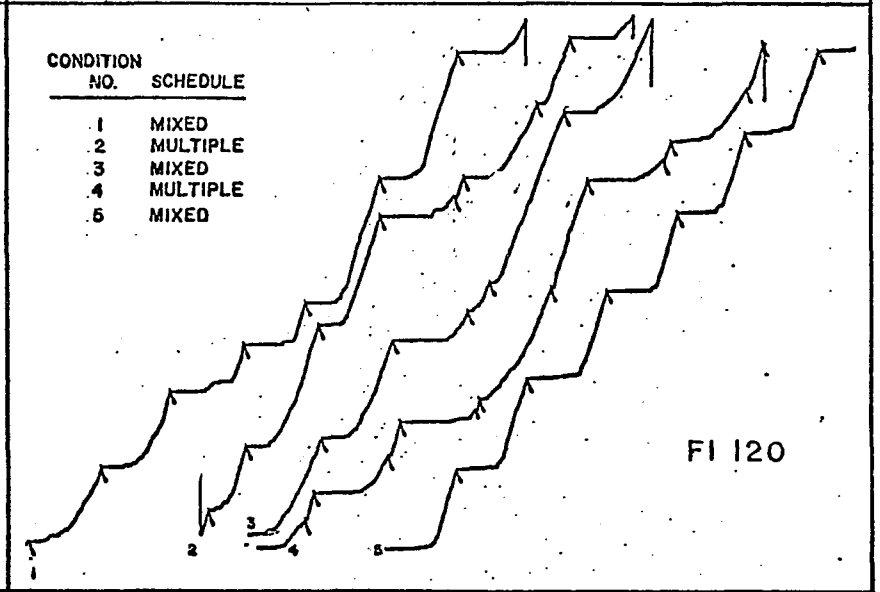
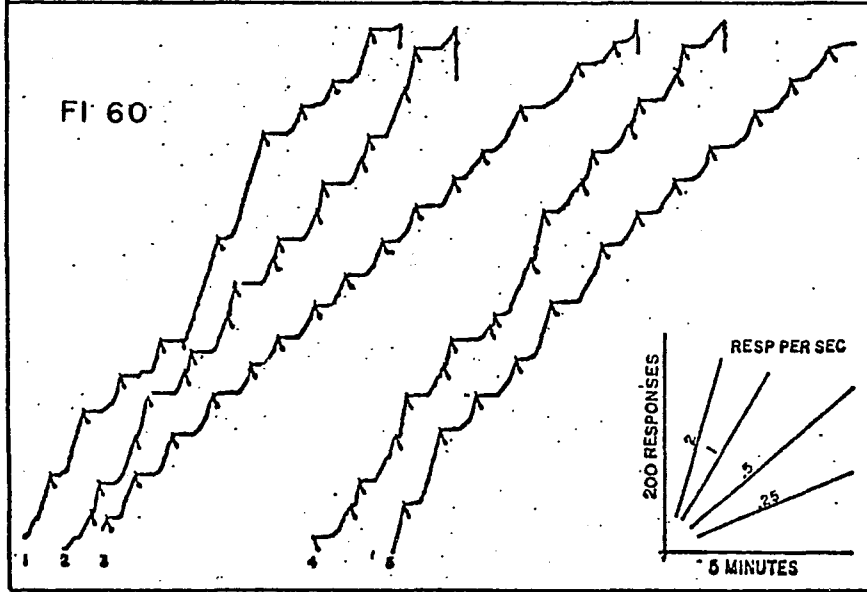
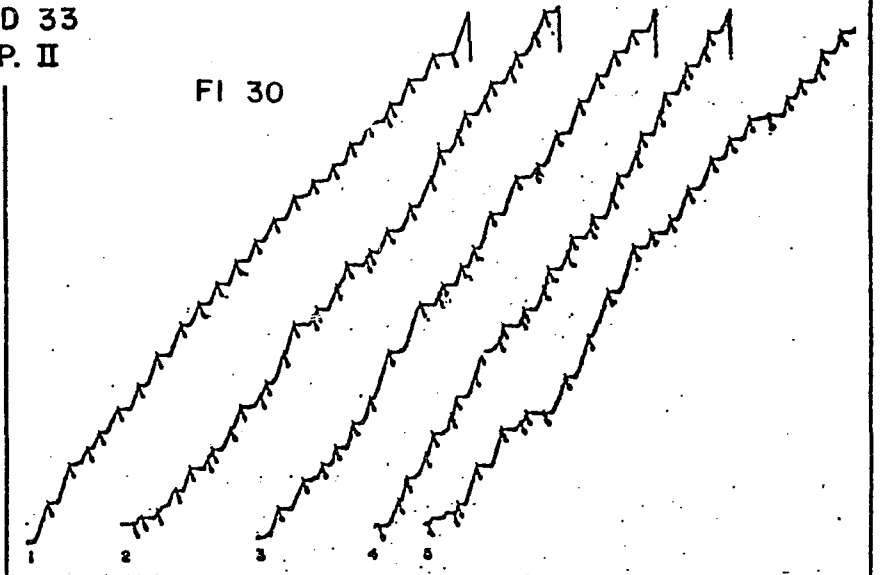


Figure 11. Partial cumulative records of Bird 39 in Exp. II.

The records were taken from the final session of each condition. The letter "a" indicates instances where the subject paused for the entire (or almost the entire) duration of the FI component (see text).

CONDITION NO.	SCHEDULE
1	MIXED
2	MULTIPLE
3	MIXED
4	MULTIPLE
5	MIXED

BIRD 39
EXP. II

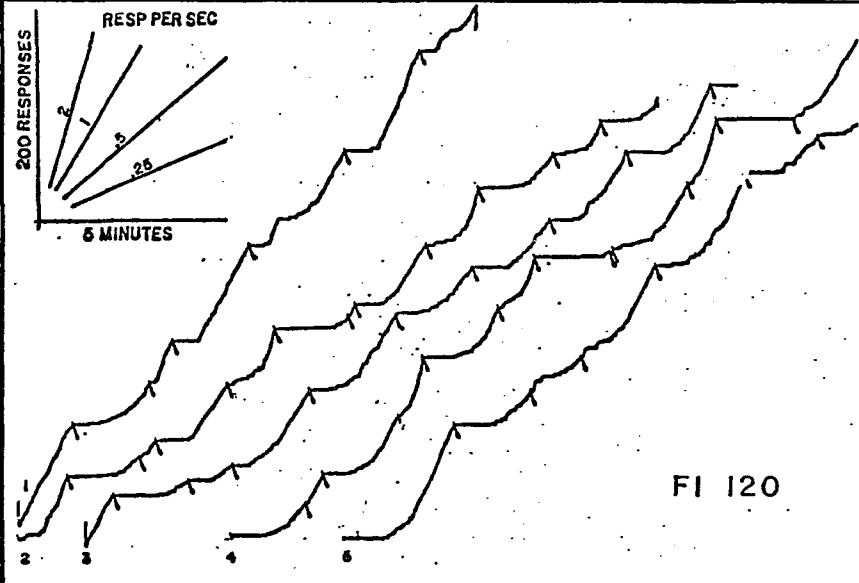
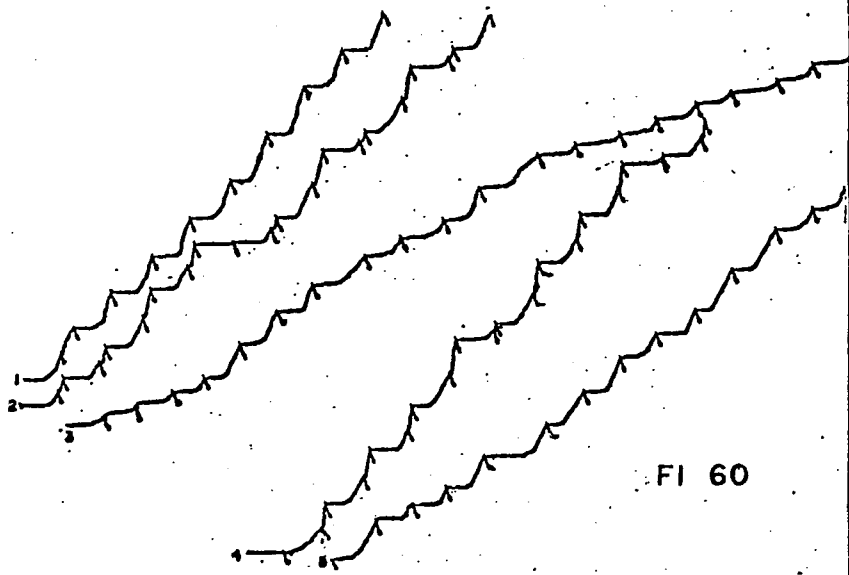
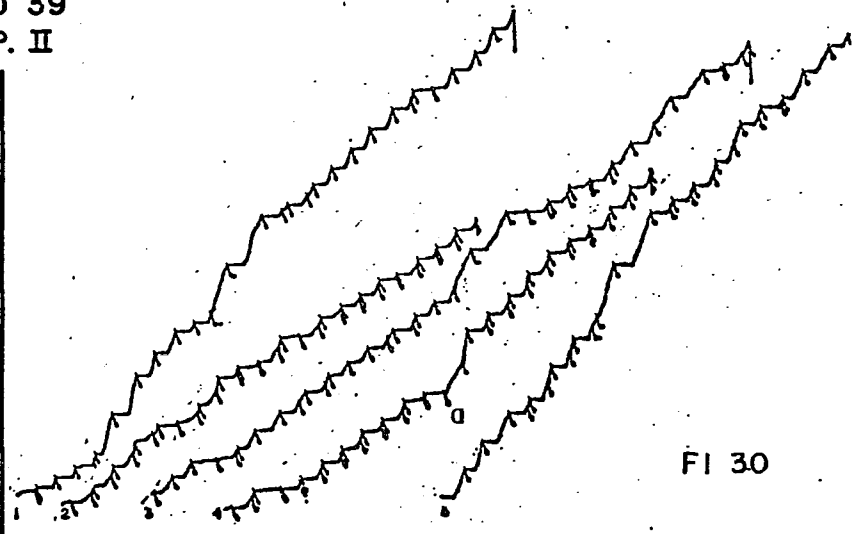
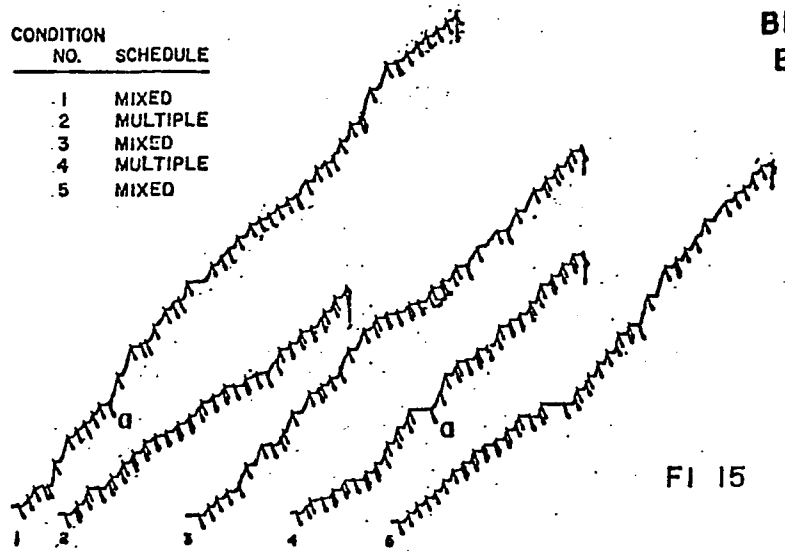


Figure 12. Partial cumulative records of Bird 35 in Exp. II.

The records were taken from the final session of each condition. The letter "a" indicates instances where the subject paused for the entire (or almost the entire) duration of the FI component (see text).

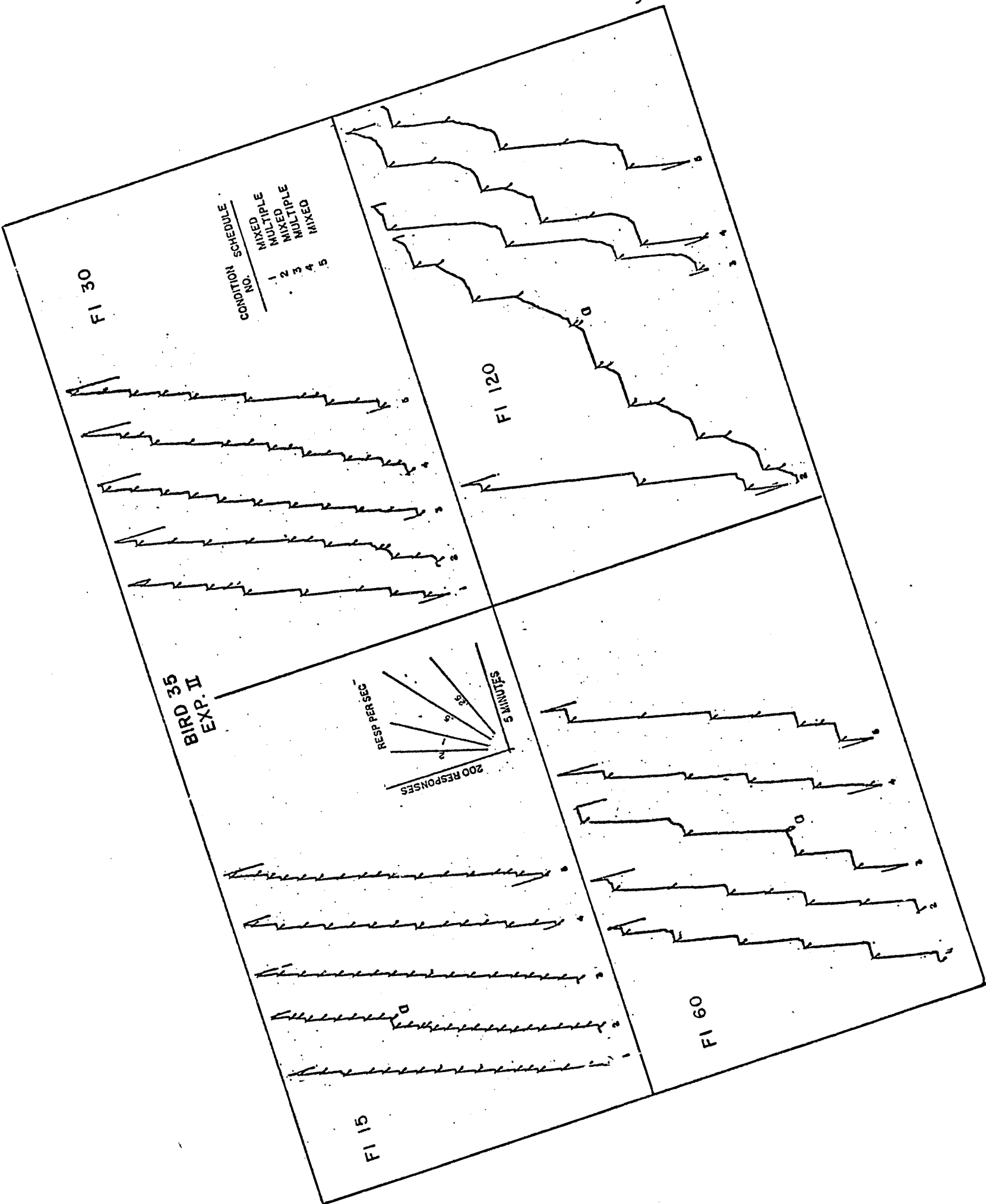
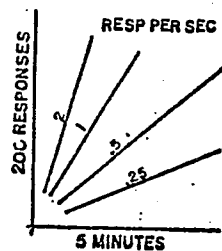
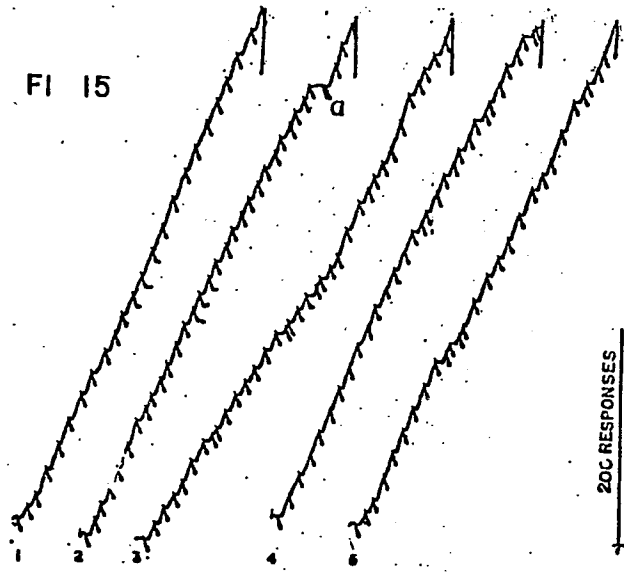


Figure 13. Partial cumulative records of Bird 38 in Exp. II.

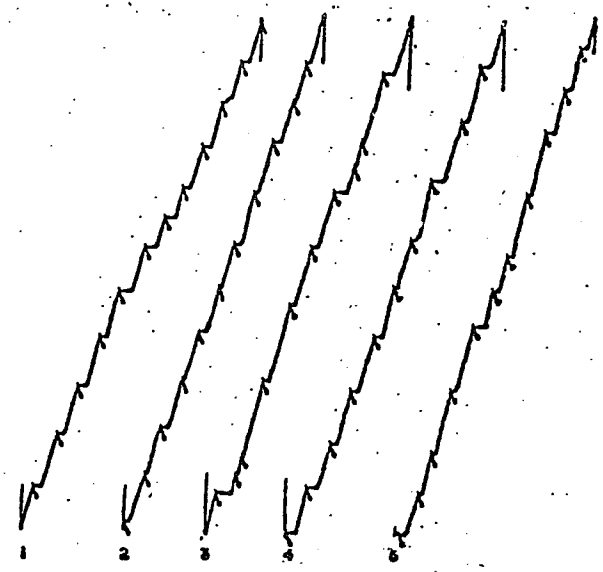
The records were taken from the final session of each condition. The letter "a" indicates instances where the subject paused for the entire (or almost the entire) duration of the FI component (see text).

BIRD 38
EXP. II

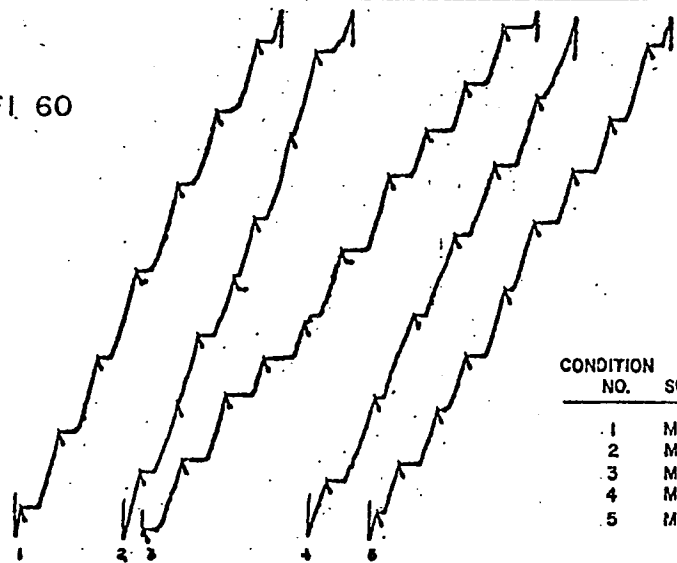
FI 15



FI 30



FI 60



CONDITION NO.	SCHEDULE
1	MIXED
2	MULTIPLE
3	MIXED
4	MULTIPLE
5	MIXED

FI 120

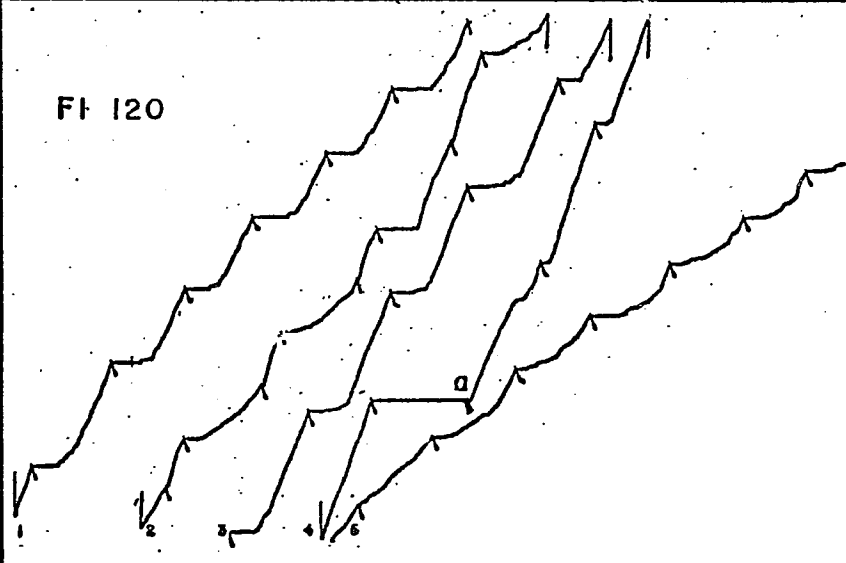
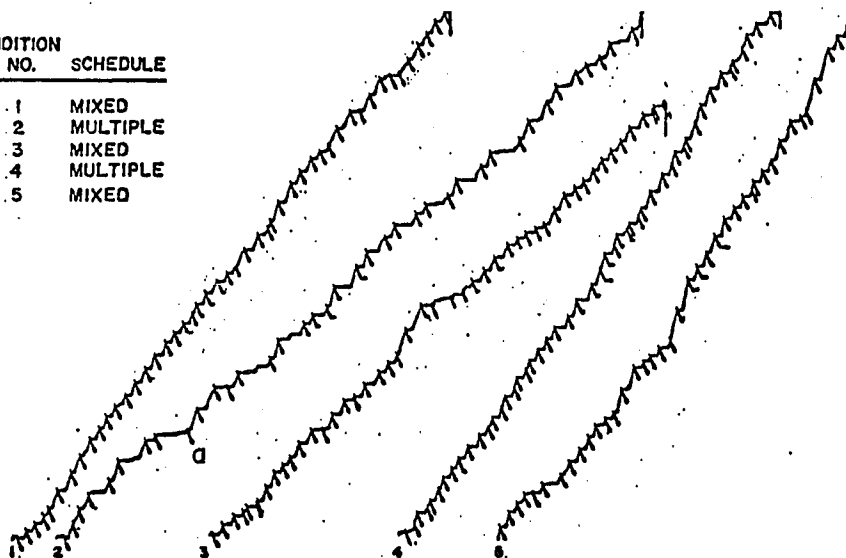


Figure 14. Partial cumulative records of Bird 37 in Exp. II.

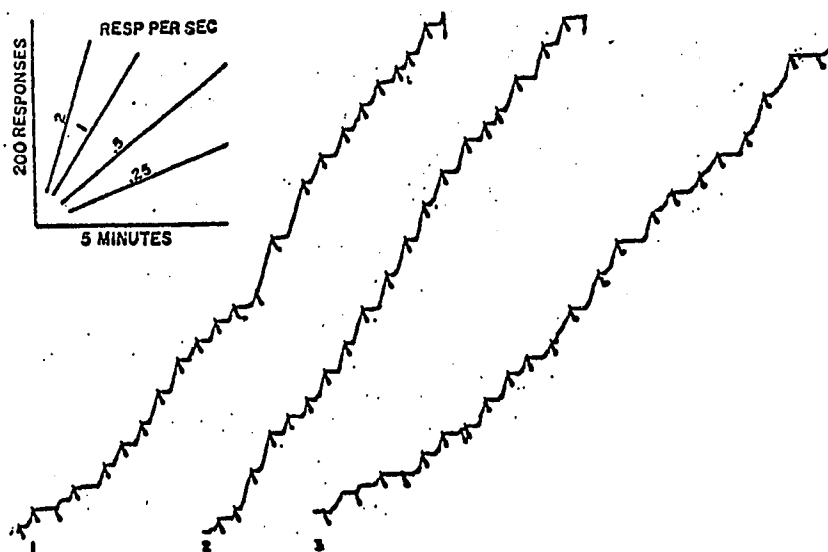
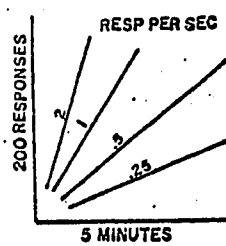
The records were taken from the final session of each condition. The letter "a" indicates instances where the subject paused for the entire (or almost the entire) duration of the FI component (see text). The subject expired after completing condition 3 of FI 30.

BIRD 37
EXP. II

CONDITION NO.	SCHEDULE
1	MIXED
2	MULTIPLE
3	MIXED
4	MULTIPLE
5	MIXED



FI 15



FI 30

Bird 37, in condition 2 of FI 15), which suggests that occurrences of reinforcement after a single response can disrupt behavior that is otherwise under precise stimulus control.

Discussion

The virtual identity of performances in FI and YR in Exp. I (see Figures 1 through 5;) demonstrates that there is a set of conditions in which interval and ratio schedules will not produce the differences in behavior typically observed under such contingencies; by "typically" is meant higher response rates under ratio schedules than under interval schedules which have been equated either for frequency of reinforcement or number of responses-per-reinforcer. The set of conditions consists of the following: (a) the interval and ratio schedules are equated in terms of the number of responses-per-reinforcer, (b) schedule changes take place after each reinforcement, and (c) exteroceptive stimuli are not differentially correlated with the schedules. The concurrent presence of these conditions represents a limiting case of such schedules, in the sense that the interval and ratio schedules are as comparable as it is operationally possible to make them, while still discernible as different schedules. If any of the conditions is not present, differential behavior patterns do emerge under each schedule, as seen in the following examples: Condition (c) was not a part of the multiple schedules of Exp. II, and during which behavior was clearly different in FI and YR (see Figures 6 through 8). In Ferster and Skinner's (1957) yoked-box experiment (pp. 399-407), conditions (a) and (c)

were present, but condition (b) was not, since the subjects were exposed to each schedule in isolation; response rates were higher under the ratio schedule. In Ferster and Skinner's alternating mixed FR 20 FI 15 min schedule (pp. 625-626), conditions (b) and (c) existed, but condition (a) did not; behavior under each component was typical of that seen under each schedule in isolation, but the schedules were very different from one another.

The results of Exp I suggest that interval and ratio schedules which are equated in terms of the number of responses-per-reinforcer may be located on a continuum defined by the "number of reinforcers delivered before schedule change." At one end of the continuum is the present case of the self-yoked procedure, in which the schedule is changed after each reinforcement, in simple alternation. At the other end is the case in which the FI schedule is presented in isolation, and where the distribution of number of responses-per-reinforcer emitted under the interval schedule serves as the independent variable in subsequent exposure to a yoked-ratio schedule in isolation. The former case does not produce different behaviors under FI and YR, as seen in Exp. I of the present study; the latter case undoubtedly would result in different behaviors in FI and YR (each in isolation), since the procedure resembles that used by Ferster and Skinner (1957) for the "master" bird in the yoked-box experiment, and in which rates were higher in the ratio schedule. Since

movement along the continuum, in a direction away from the present limiting case of simple alternation of self-yoked schedules, will ultimately result in differential behavior under FI and YR, manipulation of the parameter (of number of reinforcers before component change) is an obvious extension of the present study.

Since differential behavior does not develop under the limiting case of alternating interval and ratio schedules, the conditions of such an arrangement must somehow interfere with the normal differentiation process that usually leads to typical schedule performance when the interval or ratio schedule is presented in isolation. (The reader should note that the self-yoked procedure does not preclude the development of differential responding in FI and YR, as shown by the separation of response rates under the multiple schedules of Exp. II.) For example, a schedule of reinforcement does not produce its final effects after a single reinforcement; many reinforcers must be delivered before the typical schedule behavior emerges. In Exp. I of the present study, many reinforcers were delivered under each schedule, and yet differential behavior did not emerge. It might be argued that such an outcome was predictable, when one considers the usual course of behavioral change during exposure to an FI schedule, which follows a situation in which every response was reinforced: at first, there is quick responding immediately after reinforcement, which declines progressively as the interval continues, and which

thus resembles behavior in extinction; later, responding becomes more constant between reinforcers; still later, there is a pause after reinforcement, which is followed by an acceleration in responding as the interval continues, until interrupted by reinforcement, the so-called "scalloped" pattern (Ferster & Skinner, 1957, pp. 135-136); and finally, the scallop is replaced by a "break-run" pattern, if training is prolonged, and the interval is long (Cumming & Schoenfeld, 1958). When only a single reinforcement schedule is in effect, this kind of behavioral change is orderly and reliable, because it takes place in an environment which allows the effects of the particular contingency to be preserved from one reinforcement to the next, a process that leads to typical schedule performance. When, however, the FI schedule alternates with a yoked-ratio schedule, so that no more than one reinforcement is delivered before the schedule is changed, under such conditions, the gain from the previous reinforcement is defeated by the presence of an opposing contingency. For example, on those rare occasions that the subject pauses for the entire duration of the FI component, and thus emits only one response, there usually is a very short pause in the following YR component, and reinforcement for the single response comes quickly; the short interreinforcement time in the YR is usually followed by a very short pause in the next FI component, rather than a repetition of the long pause of the preceding FI component, which results in a high response

output, thus reversing the usual development of typical FI behavior (see "a" on the cumulative records).

The fact that FI and YR behavior did separate under the multiple schedules of Exp. II suggests that a correlated cue may be functionally similar to continuous exposure to a single schedule. That is, when stimuli are differentially associated with the schedules, reinforcement under each contingency occurs in an explicitly different context. This, of course, is a discrimination training procedure. When some particular behavior is reinforced in some particular context, that behavior is more probable when the same context reappears than when some other context appears. The presence of a correlated cue may be the consistent feature which, in effect, allows the subject to preserve its gains from one appearance of the cue and its correlated contingency to the next appearance of the same cue, in a manner analogous to successive reinforcements under the same contingency. The finding that some birds responded at a lower rate in YR than in FI under some of the multiple schedules demonstrates that, when the interval and ratio schedules are comparable, the environmental constancy provided by the correlated cue may lead the subject in the "wrong" direction; such an outcome results from the adventitious reinforcement of slower than average responding in the presence of the exteroceptive cue (cf. Herrnstein, 1970; Morse & Skinner, 1957).

Although differential behavior does not develop under the conditions of Exp. I, the FI and YR contingencies do nonetheless impact on behavior: they produce a behavioral outcome which reflects a compromise of the typical effects of each kind of schedule when presented in isolation, and which clearly is the result of schedule interactions. For example, the influence of the FI schedule is seen in the PS^{RP} s, which were the same in FI and YR, despite the constant interreinforcement time in FI and the variable interreinforcement time in YR. The PS^{RP} , however, occupied only about one-third of the FI value, which is less than the one-half to two-thirds typically seen when FI schedules are presented in isolation (Schneider, 1969; Shull, 1971). The smaller than usual PS^{RP} is attributed to the variable interreinforcement time in the YR components. The high proportion of FI components (50%) is responsible for the existence of the PS^{RP} , since the probability of responding after reinforcement under schedules with varying interreinforcement time has been shown to depend upon the minimum time between reinforcers (Catania & Reynolds, 1968). The influence of the FI schedule on response rate in YR is not clear, because data do not exist for mixed FI-YR schedules in which the components were comparable, in the sense that the term is used in this study. The influence of the ratio contingency of FI response rate is, however, very clear: corrected rates changed little with increases in FI value (see Figure

6); increases in intermittency of reinforcement usually produce decreases in the rate of responding (Ferster & Skinner, 1957; Findley, 1958; Herrnstein, 1961; Reynolds, 1961c; Wilson, 1954). These descriptions of the mutual influences of the alternating schedules demonstrate that interval and ratio contingencies have differential effects on behavior even under conditions in which they are as comparable as it is operationally possible to make them. Under such conditions, however, the effects of the individual contingencies are minimized, in the sense that typical schedule performances do not develop. When a correlated cue is superimposed on one of the schedules, the effects of the contingencies manifest themselves in full-blown fashion, as seen in the multiple schedules of Exp. II.

The finding that the corrected rates did not change with increases in FI value means that the number of responses-per-reinforcer was a direct linear function of the increased intermittency of reinforcement, which is generally confirmed in Figures 4 and 9. The linearity of the increase in extinction ratio clearly demonstrates that the pigeons were not sensitive to the yoking relation, under which the number of responses required for reinforcement in YR was subject determined, and which thus could be as few as one. In some instances, some subjects actually increased the number of responses-per-reinforcer in the multiple schedules, above that produced in the preceding mixed

schedule (Bird 35, in condition 4 of FI 15 and FI 60; Bird 38, in conditions 2 and 4 of FI 30, and condition 4 of FI 60; Bird 37, in condition 2 of FI 30). The appearance of "alternation-like" behavior notwithstanding, the lack of sensitivity to the yoking relation also demonstrates that responding in each component was generally under independent control by the correlated stimuli.

The instances of differential behavior in the mixed schedules that were observed in some birds, at some values of FI, probably reflects behavior that was still in transition at the time the experimental condition was changed. In all cases, the magnitude of differential behavior was reduced from that under the multiple schedules, and the direction of change was clearly towards non-differential behavior; what is not clear is the time that is required to reach the non-differential performance. This interpretation is suggested by several observations: (1) some birds showed almost no differential behavior at the time the experimental condition was changed (Birds 37 and 38), (2) for three subjects (Birds 33, 35, and 39), the degree of differential behavior was greatest at the smaller values of FI, which suggests that the time needed for recovery of the non-differential performance may be a function of the parameter value, and (3) although there were individual differences in the degree of differential behavior, the group data show that the greatest amount was observed in the condition that had the fewest number of

sessions: condition 5 of FI 30 (see Table 2). This hypothesis may be tested in subsequent experiments, either by increasing the number of sessions, or by interpolating a period of extinction between each experimental condition (cf. Clark, 1959).

Finally, it may be stated that, when interval and ratio schedules are made as comparable as possible, as was the case in Exp. I and the mixed schedules of Exp. II, the schedules will not produce the differences in behavior typically observed under such schedules. Thus, any description of differences in the behavioral effects produced by interval and ratio schedules is incomplete without taking account of the conditions under which differential behavior does not emerge. The self-yoked procedure, and its variations, may shed more light on how differential behavior does develop when the schedules are made less comparable.

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