

CONJUNCTIVE SCHEDULES OF RESPONSE-DEPENDENT AND RESPONSE-INDEPENDENT REINFORCEMENT¹

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Pigeons received food when they emitted the number of responses specified by a fixed-ratio schedule, and the time specified by a fixed-time schedule had elapsed. The order of meeting the response and time requirements was irrelevant. In different conditions, stimuli signalled completion of one, both, or neither requirement. Ratio size interacted with stimulus condition to determine performance. When a stimulus signalled the end of the fixed-time period, under all ratios the birds tended to respond after the stimulus appeared. When stimuli followed both components, small ratios produced responding during the fixed-time period, and other ratios resulted in responses after the time period had elapsed. With either no stimulus changes, or with a stimulus correlated with completion of the ratio alone, responding first increased and then decreased as the ratio increased. Low and high ratios produced stable response frequencies and patterns in successive intervals. Intermediate ratios resulted in two types of performance. Intervals with long initial pauses and few responses during the fixed-time period were followed by intervals with short pauses and numerous responses and *vice versa*. The source of these dynamic effects was hypothesized to be number of responses per reinforcer in one condition and response-reinforcer contiguity in the other.

Key words: dynamic effects, stereotypic effects, conjunctive schedule, fixed-ratio schedule, fixed-time schedule, stimulus control, ratio size, key peck, pigeons

The history of reinforcement theory has been characterized by much debate and little agreement about how and why reinforcement occurs. At the level of operational definition, however, Morse's (1966, p. 53) description of a reinforcer is reasonably representative (with allowance for differences in terminology): "Operationally, an event is identified as a positive reinforcer if the frequency of responses of a given class (operant) increases when the presentation of the event is made contingent upon a response of that class." A reinforcer is manifested by the increased frequency (or by some other estimate of probability or strength) of the response followed by the (reinforcing) event.

Although the definition does not encompass all effects of reinforcers (*cf.* Morse, 1966), it perhaps has played a role in the emphasis on

response repetition in the analysis of reinforcement. With recognition that reinforcers always occur in the context of some schedule, concern with the distribution of responses in time supplemented interest in response frequency. The repetitive nature of these patterns under the common reinforcement schedules, although not part of the definition of the reinforcer, further emphasized that reinforcers produce constancy. The tendencies of a schedule to generate repetition have been referred to as *stereotypic effects* (Zeiler, *in press*). Recently, additional properties of reinforcers have been recognized (*e.g.*, Hearst and Jenkins, 1974; Staddon and Simmelhag, 1971), but these also do not relate to the ability of reinforcement schedules to generate change rather than constancy. The need to supplement descriptions of central tendency with quantitative measures of variability has always been recognized, but variability in this sense relates to the reliability of stereotypic effects and the possibility of unknown sources of control. However, systematic changes may not represent uncontrolled variability, but actually may reflect strong effects of a schedule stemming from continually changing relations between

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ongoing behavior and reinforcer presentation. These are the *dynamic effects* of a schedule (Zeiler, *in press*).

Although Skinner noted some dynamic effects in 1933, the potential of a schedule to produce orderly but continually changing performance has not received much attention. Variation can be required for reinforcer delivery (e.g., Blough, 1966), but schedules also produce undemanded variation. Dynamic effects have appeared when aspects of behavior irrelevant to reinforcer presentation have been considered. For example, fixed-interval (FI) schedules require no responses before the end of the interval and specify nothing about the duration of the initial pause. They generate cyclicities in the number of responses emitted in successive intervals (Dews, 1970; Ferster and Skinner, 1957) and in pause duration (Shull, 1971). Yet, nonrequired aspects of performance do not always display such variation. Fixed-interval schedules require no specific temporal distribution of responses, but the same pattern repeats from one interval to the next. In fact, patterning is one of the most stable aspects of performance.

The extent to which a schedule specifies what must occur as prerequisite for reinforcer delivery limits the variation that can appear. The common response-dependent schedules prescribe the response occurring just before reinforcer delivery and lead to increased frequency of that response. Other aspects of behavior may or may not change. In contrast, response-independent schedules lead to continuous change, but also to difficulty in recording the behavior predominating at any given time. The idea leading to the present schedule was that a combination of response-dependence and response-independence might produce observable dynamic effects on both response rate and patterning.

In a conjunctive schedule, reinforcer presentation follows conformity to two or more separate requirements. The order in which they are met is irrelevant. The present conjunctive fixed-ratio (FR) fixed-time (FT) schedule arranged food presentation when a pigeon emitted at least the number of responses required by the FR and the time interval specified by the FT had elapsed. If the ratio was completed before the FT period ended, food occurred as soon as the time elapsed; if the ratio was not completed during

the FT period, food was given as soon as the required number of responses was emitted. A tendency to respond early meant that the FR probably would be completed before the FT. If so, the pigeon might or might not still be pecking just before food delivery. A long initial pause, however, meant that food probably would immediately follow the peck completing the ratio. Nothing in the procedure precluded the same pattern of responding from one interfood interval to the next. However, if performance early in one interval reflected the behavior contiguous with the reinforcer in the one preceding, dynamic effects would appear. Intervals terminating with completion of the FR would be followed by intervals in which pecking was initiated early, because pecking had immediately preceded the reinforcer. But this in turn would mean that the interval terminated with the FT, thereby resulting in reduced tendency to respond at the start of the next interval, because behavior other than pecking could just have been followed by the reinforcer. The result would be cyclicity with short pauses followed by long and *vice versa*.

Ratio values were manipulated to observe the full range of effects that might occur under conjunctive FR FT schedules. This also permitted comparison of the effects of ratio size in conjunctive FR FT and conjunctive FR FI (Herrnstein and Morse, 1958) schedules. Previous research with conjunctive FR FT schedules involved either FR 1 (Morgan, 1970; Shull, 1970; Staddon and Frank, 1975) or a single larger FR (Barrett, 1975; Powers, 1968). Although the conjunctive FR FT schedule is analogous to the discrete-trial arrangement called "controlled interval of reinforcement" (Logan, 1960), the response requirement does not seem to have been varied parametrically in that context either.

Other manipulations involved stimuli correlated with the completion of none, one, or both components. Sensitivity to stimulus consequences with conjunctive schedules (Barrett, 1975) suggested that such manipulations would clarify how conjunctive FR FT schedules influence performance.

METHOD

Subjects

Five White Carneaux pigeons of undetermined sex were maintained at 80% of their

free-feeding weights. Birds P-1, P-15, P-42, and P-46 had previous experience with a variety of schedules of positive reinforcement, and P-149 was experimentally naive, except for magazine and key-peck training.

Apparatus

A single-key pigeon unit contained a 2-cm diameter response key (R. Gerbrands Co.), operated by a force exceeding 0.18 N, and located 21.5 cm above the floor. The key could be transilluminated by two 7-W blue, red, or green lamps. The reinforcing stimulus was Purina Pigeon Checkers, the birds' standard diet, presented for 4 sec through a 5.1-cm square aperture located 8 cm below the key. When the food hopper was activated, a 1-W white lamp illuminated the aperture, and the key was dark for the final 3.5 sec of the cycle. A GE 25T10/1F lamp in series with a 300-ohm resistor, mounted on the upper-right corner of the panel bearing the key and hopper, provided general illumination except during feeder cycles. White noise masked extraneous sounds. The experimental chamber was located in a separate room from the control and recording equipment.

Procedure

The prevailing schedule was conjunctive fixed-ratio (FR) fixed-time (FT): food was presented whenever the number of pecks specified by the FR component was emitted and the time specified by the FT component had elapsed. All timing was from the end of the preceding food presentation. The sequence in which the response and time requirements were met was irrelevant. For example, in the conjunctive FR 100 FT 10-min schedule, if 100 or more responses had been emitted before 10 min elapsed, food was presented independent of responding at 10 min. If fewer than 100 responses had occurred at 10 min, food followed the hundredth response.

The FT value was always 30 min for P-1, 5 min for P-15 and P-149, and 10 min for P-42 and P-46. Thus, FT value was varied across birds. Under each condition, the value of the FR component was increased until responding either was no longer maintained or decreased markedly.

The minimal criterion for a schedule change was 20 sessions with no monotonic increase or decrease in the total number of responses

emitted in each of the last five sessions. The responses in each of these five sessions had to be within 10% of the mean number over the five sessions combined. If, however, response rate was 0.00 responses per second for three consecutive sessions, the schedule was terminated. Occasionally, more than 20 sessions were conducted, even though the stability criterion had been met (to determine if changes might occur). No such changes ever appeared.

Sessions were conducted five days per week. They terminated either after 10 food presentations (one delivered at the start of the session and the other nine delivered according to the prevailing schedule) or after 4 hr when the FT component was either 5 or 10 min and after 14 hr with FT 30-min. Occasionally, a session involving FT 10-min was allowed to continue for 8 hr. The total number of sessions was 1453 for P-1, 930 for P-15, 878 for P-42, 691 for P-46, and 637 for P-149.

Seven conditions each involved a range of FR values, and differed in the stimulus consequences correlated with the components of the conjunctive schedule. Either no stimulus changes occurred (Conditions 1, 3, 5, 7), distinctive stimuli marked completion of both the FR and the FT (Condition 2), a stimulus signalled only completion of the FR (Condition 4), or a stimulus signalled only completion of the FT (Condition 6). One bird (P-1) had every condition, and one had each condition involving a stimulus change as the first with exteroceptive stimuli. This procedure produced variety in the sequence of conditions across subjects and thereby provided some control for possible effects of one stimulus condition on the others. Table 1 shows the sequence of conditions for each bird.

No stimulus change. The key remained blue except during the final 3.5 sec of the 4-sec feeder cycle. Ratio values were selected from the following set: 0, 1, 10, 25, 50, 100, 150, 200, 250, 300, 400, 500, 700, 900, 1100. Ratios were imposed first in an ascending and then a descending order, with occasional reversals. Sometimes the sequence started with FR 1 and sometimes with FR 100.²

Bird P-1 had this arrangement before and after the three conditions involving stimulus

²The sequence of schedules differed among birds and conditions. A detailed description of the sequence is available from the author on request.

Table 1
Sequence of Conditions and Schedules

| Condition | Schedule Number | | | | |
|---------------------------------|-----------------|-------|-------|-------|-------|
| | P-1 | P-15 | P-42 | P-46 | P-149 |
| 1. No Stimulus Change | 1-16 | 1-13 | | 1-14 | |
| 2. Stimulus Change on FR and FT | 17-31 | 14-28 | | 15-29 | |
| 3. No Stimulus Change | 32-37 | 29-32 | | 30-34 | |
| 4. Stimulus Change on FR | 38-47 | 33-41 | 1-11 | | |
| 5. No Stimulus Change | 48-50 | 42-43 | 12-15 | | |
| 6. Stimulus Change on FT | 51-61 | | 16-28 | | 1-18 |
| 7. No Stimulus Change | 62-72 | | 29-41 | | 19-34 |

changes correlated with components, thereby having four separate series of exposures. The first involved schedules ranging from FR 0 (simple FT 30-min schedule) to FR 300, the second from FR 50 to FR 300, the third from FR 100 to FR 300, and the fourth from FR 0 to FR 300. Bird P-15 had this arrangement three times. The first set of schedules ranged from FR 0 to FR 300, the second from FR 50 to FR 200, and the third from FR 100 to FR 200. Bird P-42 had this condition twice. The first set of schedules ranged from FR 25 to FR 300, and the second from FR 0 to FR 400. Bird P-46 also had this arrangement twice. The first set of schedules ranged from FR 0 to FR 300, and the second from FR 50 to FR 250. Bird P-149 had the condition once with schedules ranging from FR 0 to FR 1100.

Stimulus change on FR and FT. The key remained blue until either the FR or the FT requirement was met. It changed to green with completion of the FT or to red with completion of the FR. It remained green or red until the second component was completed, when 0.5 sec of the color correlated with the component completed last accompanied food delivery. For example, if the schedule was conjunctive FR 100 FT 10-min, the key was blue at the outset. If 10 min elapsed before emission of 100 responses, the key became green until the hundredth response produced 0.5 sec of red at the beginning of the 4-sec magazine cycle. If 100 responses occurred before 10 min, the color changed from blue to red after the hundredth response, and, when 10 min elapsed,

0.5 sec of green accompanied food presentation.

Birds P-1, P-15, and P-46 had this condition. All had the same sequence of fixed ratios: 1, 25, 10, 15, 20, 25, 50, 100, 150, 200, 300, 100, 25, 10.

Stimulus change on FR. The key was blue until the FR requirement was met and changed to red when the ratio was completed. Stimuli did not change with respect to the FT component. If the FT was completed before the FR, 0.5 sec of red accompanied food presentation.

Birds P-1, P-15, and P-42 had this condition. The sequence of fixed ratios was: 1, 25, 50, 100, 150, 200, 250 (P-1 and P-42), 300 (P-42), 100, 50, 25.

Stimulus change on FT. The key was blue until the FT period elapsed and then the color changed to green. Stimuli did not change with respect to the FR component. If the FR was completed before the FT, 0.5 sec of green accompanied food presentation.

Birds P-1, P-42, and P-149 had this condition. The sequence of fixed ratios was 1, 10, 25, 50, 100, 150, 200, 250, 300 (P-42 and P-149), 400 (P-42 and P-149), 500 (P-149), 700 (P-149), 900 (P-149), 1100 (P-149), 700 (P-149), 100, 50, 25.

RESULTS

Unless otherwise noted, under each condition replications of FR values yielded mean response rates for the last five sessions of each exposure that were within 10% of each other. This also was the case for the other dependent variables described below. Quantitative data shown are the averages of all the final five-session means for a given stimulus condition and FR size, and these always closely represented the means for individual sessions.

No Stimulus Change

Figure 1 shows representative cumulative records for one bird. Although all birds did not reveal identical performance at each FR value, increases in ratio size produced sufficiently similar patterns of responding for these sample records to be representative of trends appearing with all. Under FR 0 (simple FT schedule), few responses occurred and the prevailing pattern was a pause followed by variable response rate. The FR 1 schedule did not generate marked changes. At FR 10 and FR

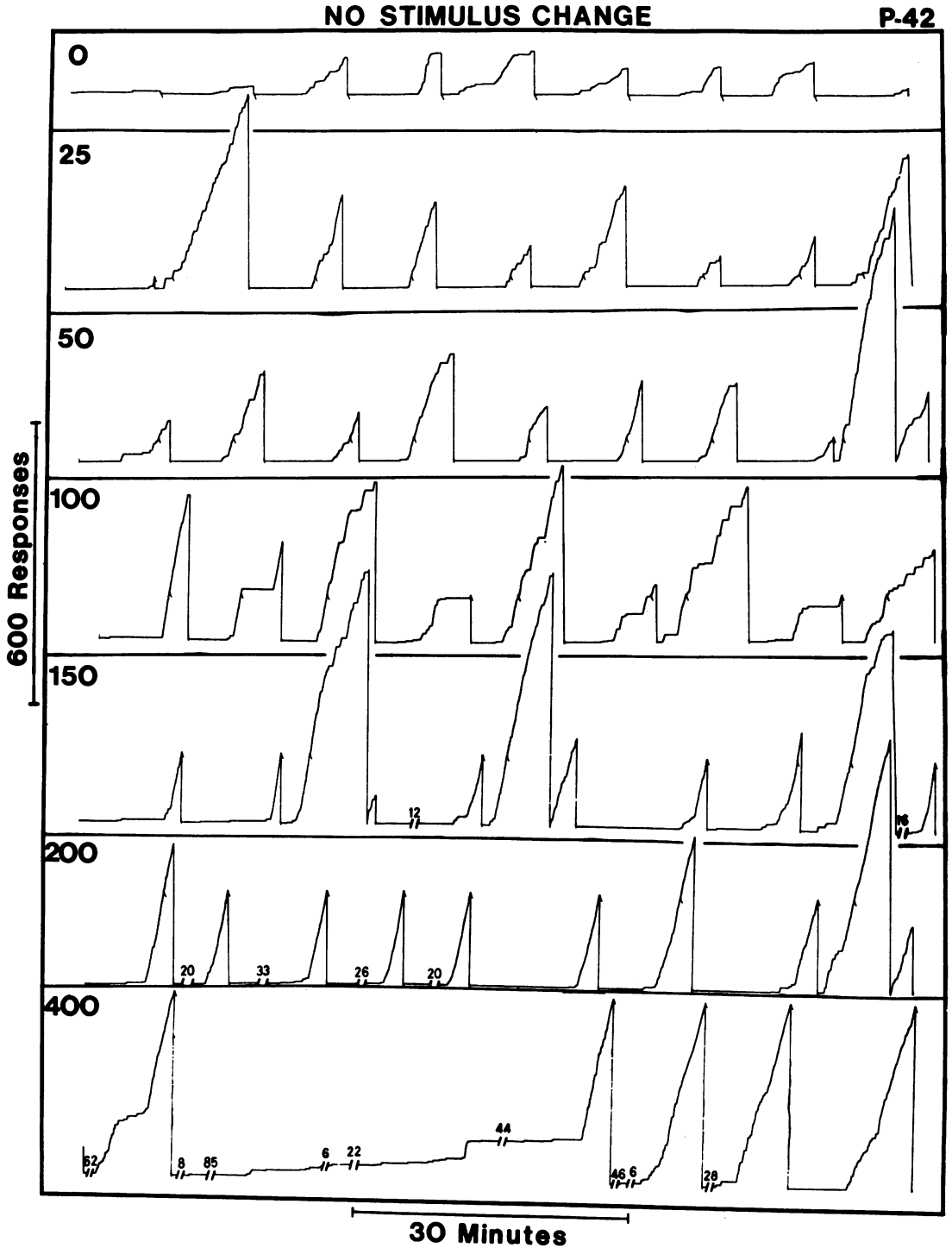


Fig. 1. Cumulative records for P-42 with stimulus changes correlated with neither component. Numerals in the upper left of each segment indicate the FR value. Offsets of the response pen indicate completion of the FR. Breaks in the record and numerals above them indicate the minutes without a response at that point. The response pen reset at food presentation and after 550 responses.

25, an initial pause was followed by a steadier rate and an increased level of responding.

At FR 50, FR 100, and FR 150 (except with P-149), the number of intervals increased in which the FR requirement was met after the FT period elapsed. In addition, performance was not constant in successive intervals. Changing performance from one interval to the next is shown most clearly in the FR 100 and FR 150 segments of Figure 1. Responding in one interval sometimes resembled that of the interval preceding, but at other times it did not. Instead, intervals with long pauses and minimal responses were followed by intervals with short pauses and many-fold more responses. A high level of responding tended to appear if the interval preceding had ended with a response (FR requirement met after the FT elapsed), and long pauses tended to prevail if the interval preceding ended when the FT elapsed (FR requirement met during the FT period). Alternations in number of responses in successive intervals appeared at these ratios with P-149 as well, except that the FR always was completed during the FT period. This same phenomenon (alternation in response number but not in whether ratios were completed during and after the FT) characterized P-15 at FR 25. Alternations between ratios completed during and after the FT period appeared at FR 500 and FR 700 with P-149 and at FR 50 with P-15.

With still larger ratios than those revealing the alternation pattern, responding was maintained increasingly poorly. Occasional intervals displayed early responding at a high rate. Finally, at the highest ratios, responding either was not maintained at all, or initial pauses extended well beyond the FT period and additional pauses interrupted responding.

The sequential effects in successive intervals that were indicated by the cumulative records were analyzed further by one-sample runs tests (Siegel, 1956). These tests were conducted on the duration of the initial pause in successive intervals. Consideration of number of responses instead of pause duration resulted in the same conclusions, but pause duration had the advantage of being more readily applicable to the other conditions as well. Mean pause duration over the last five sessions established the reference point. The runs test determined whether the number of transitions between long and short pauses (defined in terms of

pauses longer and shorter than the mean) was more or less than would be expected by chance. Starting with the first pause of each session, a run was defined as a succession of identical pauses followed by a different pause or by the end of the session. The maximum number of runs in a session was nine and would occur if long and short pauses alternated. The minimum number was one and would occur if all of the pauses were longer or shorter than the five-session mean. Over the five sessions, the maximum number of runs was 45 and the minimum was five.

For the present data, more than 30 or fewer than 15 runs had a probability of occurring by chance of $p < 0.05$. Figure 2 (filled circles) shows the number of runs at each FR value. For all birds, the number of runs exceeded 30 at some ratio, and all displayed the same trend for runs first to increase and then decrease as a function of ratio size. For P-1, P-42, and P-46, the most runs occurred when successive intervals tended to be terminated first by one and then by the other component of the conjunctive schedule. For P-15 and P-149, the most runs appeared when intervals ended with completion of the FT (FR completed during the FT period), but long and short pauses alternated during the FT.

Fewest runs appeared at low ratios where variability in pause duration about the mean was small, or at high ratios where responding was not well maintained. In the first case, the runs analysis seemed essentially trivial, because of the small range in pause durations. In the second, the decreased number of runs stemmed from the tendency for pauses to lengthen over the session.

Figure 3 shows the number of responses emitted during the FT period and the response rate after the FT had elapsed. The functions accurately summarize performance averaged over entire sessions, but they were representative of individual intervals only for the ratios that did not produce alternating patterns from one interval to the next. Because response rate after the FT was averaged only over intervals in which the FR was completed after the FT, the data are representative of at least a portion of the intervals in each session under every ratio.

Responding was related to ratio size. As the ratio was raised, responding during the FT first increased and then decreased. Similar

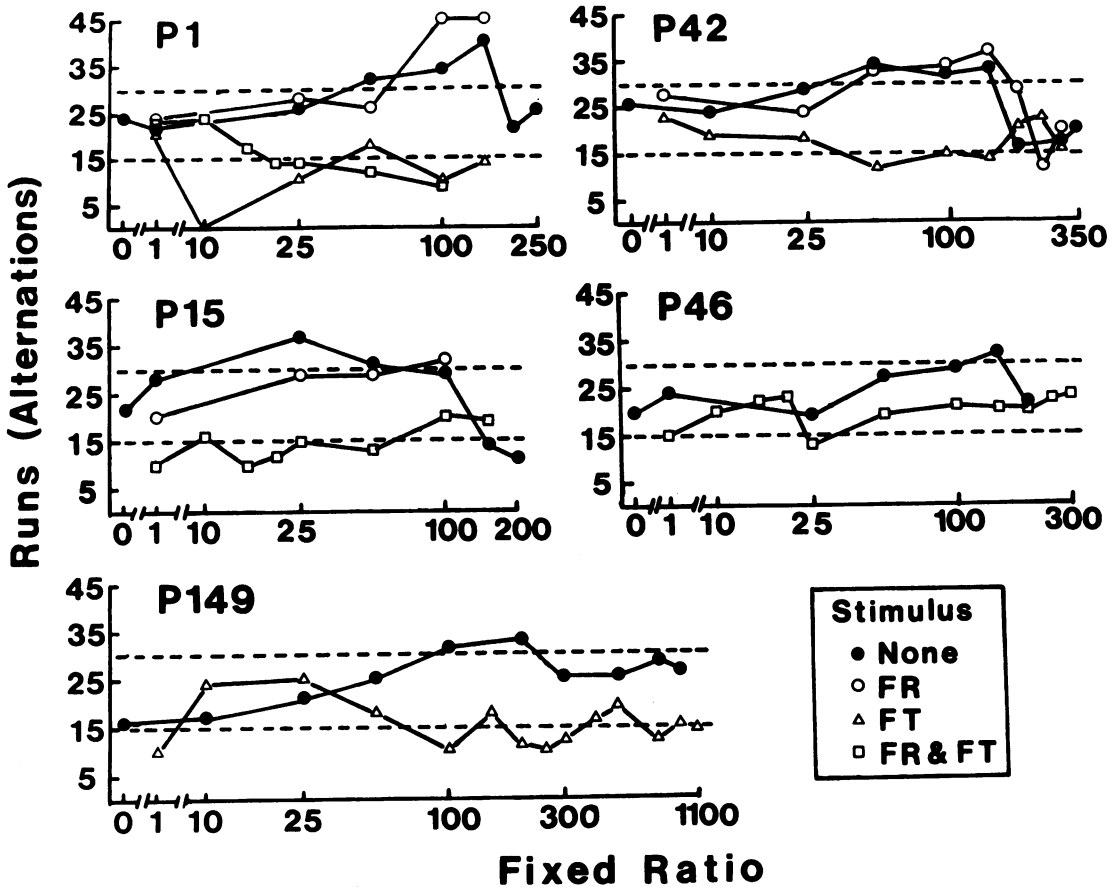


Fig. 2. Number of runs based on deviations about the mean pause duration. After FR 10, values on the horizontal axis are plotted logarithmically. Points above and below the upper and lower horizontal dashed lines respectively had a probability of occurring by chance of $p < 0.05$. Data are shown separately for each of the four stimulus conditions.

curves for the different birds indicated the independence of these functions from the FT parameter (5, 10, or 30 min). The atypically high level of responding with P-149 did not appear related to the FT value, because P-15, the other bird with FT 5-min, responded the least. The major difference between subjects, then, was in the absolute values of the dependent variables, the most noticeable being the high level of responding by P-149 at ratios as high as FR 1100.

Table 2 shows the average time from food presentation to the first response (pause duration) and interfood time. Average pause duration tended to increase with ratio size, but the trend always reversed at intermediate ratios (when the alternation in successive patterns prevailed). The time between food presentations was stable at the minimal level estab-

lished by the FT period at the lower ratios and increased monotonically thereafter.

Stimulus Change On Fixed Ratio and Fixed Time

Figure 4 shows representative cumulative records for the schedules involving stimuli correlated with both the FR and the FT components. Food presentation could occur in the presence of either green or red, depending on the order in which the time and the response requirements were completed. With FR 1, the response occurred immediately, the stimulus changed, and either no or a few responses appeared thereafter. All food presentations occurred as soon as the FT elapsed. Under FR 10, the same basic pattern was preserved: the response requirement was met early and was followed by a pause often lasting until food

NO STIMULUS CHANGE

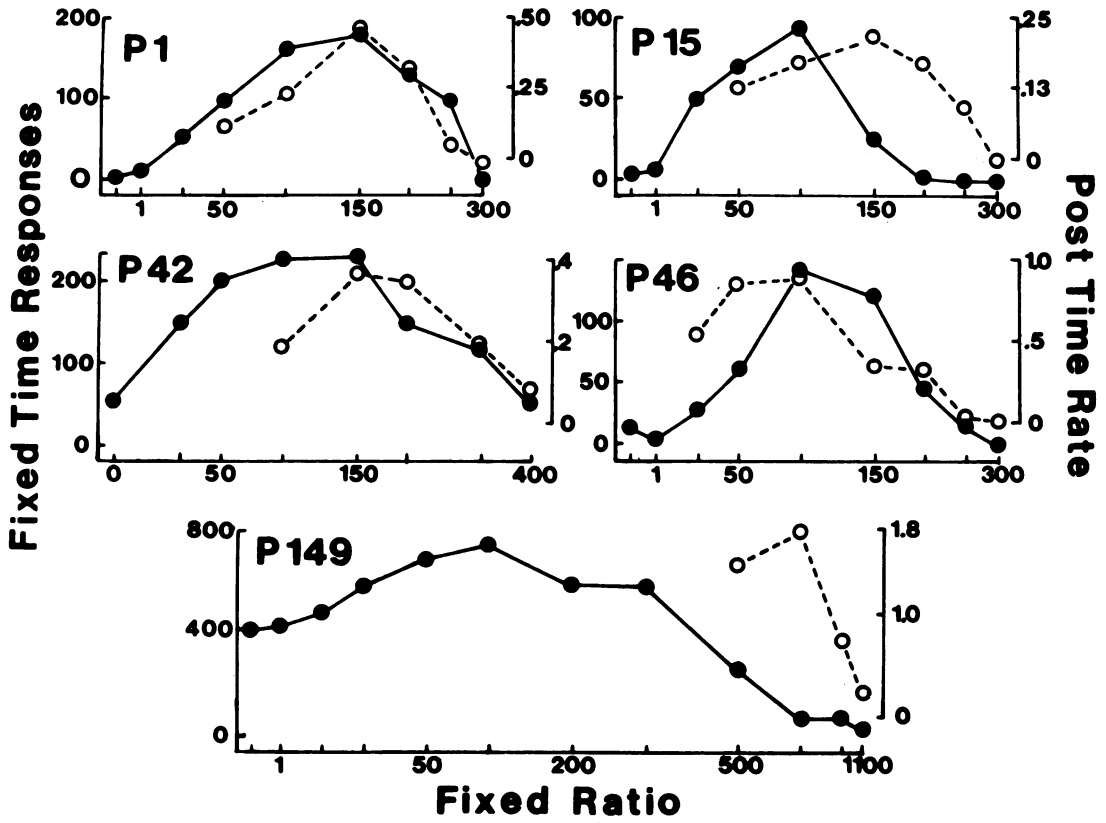


Fig. 3. Mean responses during the FT period (filled circles) and responses per second after the FT period ended for the no-stimulus change condition. Scales differ among birds, and values on the horizontal axis are spaced according to a logarithmic scale distorted at the ends for convenience of presentation.

Table 2
Pause Duration and Interfood (S^2) Time:
No Stimulus Change

| | P-1 | | P-15 | | P-42 | | P-46 | | P-149 | |
|---------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| | Pause (sec) | S^2 (sec) | Pause (sec) | S^2 (sec) | Pause (sec) | S^2 (sec) | Pause (sec) | S^2 (sec) | Pause (sec) | S^2 (sec) |
| FR 0 | 496 | 1800 | 133 | 300 | 280 | 600 | 123 | 600 | 37 | 300 |
| FR 1 | 298 | 1800 | 135 | 300 | | | 266 | 607 | 36 | 300 |
| FR 10 | | | | | 330 | 600 | | | 43 | 300 |
| FR 25 | 634 | 1826 | 122 | 300 | 357 | 600 | 299 | 613 | 21 | 300 |
| FR 50 | 1027 | 1938 | 112 | 317 | 308 | 600 | 229 | 613 | 49 | 300 |
| FR 100 | 442 | 1924 | 124 | 335 | 176 | 636 | 113 | 609 | 43 | 300 |
| FR 150 | 1047 | 1957 | 225 | 927 | 376 | 775 | 191 | 907 | | |
| FR 200 | 1342 | 2254 | 781 | 1472 | 429 | 788 | 337 | 1053 | 40 | 300 |
| FR 250 | 1620 | 3135 | 2154 | 3009 | | | 609 | 5115 | | |
| FR 300 | a | a | a | a | 945 | 1600 | 1195 | 16290 | 72 | 300 |
| FR 400 | | | | | 1397 | 4603 | | | | |
| FR 500 | | | | | | | | | 116 | 525 |
| FR 700 | | | | | | | | | 155 | 650 |
| FR 900 | | | | | | | | | 393 | 1424 |
| FR 1100 | | | | | | | | | 124 | 4896 |

*Pause lasted for entire session, and no food presentations occurred.

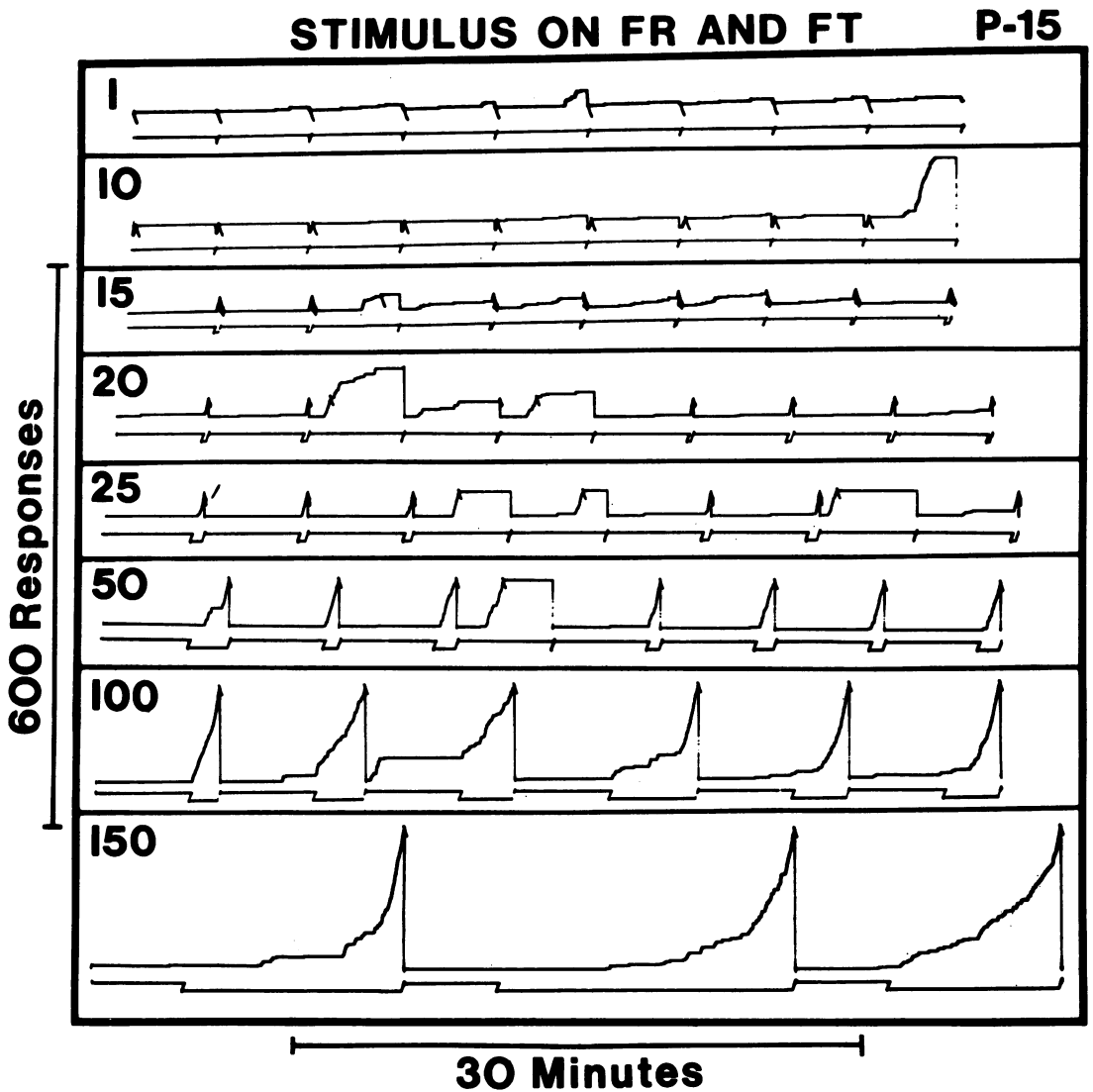


Fig. 4. Cumulative records for P-15 with stimulus changes correlated with completion of both components. The event pen offset at the end of the FT period and returned to position at food presentation. Other details as in Figure 1.

delivery. At either FR 1 or FR 10, therefore, food followed a long interval of red and was accompanied by 0.5 of green. Responding was largely confined to the presence of blue.

This pattern changed with FR 15 and became still more pronounced in the new form with larger ratios. Comparison of the records for FR 10 and FR 15 in Figure 4 shows the shift from responding at the start of the interval to responding delayed until the stimulus change signalled the end of the FT period. Now, food presentation followed exposure first to blue and then to green and was accompa-

nied by 0.5 sec of red. Blue now controlled pausing rather than pecking. With ratios up to FR 50, the pattern occasionally and unpredictably reversed to that seen with FR 1 and FR 10. Under the higher ratios, the initial pause lasted throughout the FT period and sometimes continued after the change from blue to green signalled that the FT period had elapsed. At the highest ratios (not shown in Figure 4), responding was not maintained.

Figure 2 (squares) shows the results of the runs-test analysis conducted on successive pause durations. In no instances did more runs

(alternations between long and short pauses) occur than would be expected by chance. Every bird, however, showed instances of fewer than 15 runs ($p < 0.05$). The tendency was either for long and short pauses to occur at random, or for each to occur in clusters. In short, pausing in one interval either resembled that of the preceding interval, or was unpredictably variable about the mean.

Figure 5 shows that the number of responses exceeded the FR value only at FR 1 and FR 10 for P-1 and P-15 and up to FR 20 for P-46. The number of responses during the FT period decreased as the ratio was raised further, and response rate after the FT elapsed was inversely related to FR size as well. The decreased rate of responding after the stimulus signalled completion of the FT period stemmed from continued pausing and not from changes in rate once responding began. Table 3 shows that average initial pause duration increased along with FR size. The time between food presentations was the minimum

permitted by the FT component under low ratios and increased thereafter. All of these summary data were representative of session means and of the majority of individual intervals as well.

Stimulus Change On Fixed Ratio

When the only color change was from blue to red on completion of the fixed ratio, performance once again was determined by FR size. As shown in Figure 6, FR 1 produced a brief pause most often followed by one response and a pause until food delivery. A few intervals had additional responses. At FR 25 and FR 50, all of the responses occurred before the stimulus change, and the number of responses emitted matched the number required. Intervals began with a pause, followed by a substantial response rate usually maintained until the twenty-fifth or fiftieth response produced the signal that the FR was completed.

Two different patterns emerged at FR 100. One consisted of an initial pause extending well beyond the FT period, followed by a high response rate terminated by food delivery. The second was an initial pause shorter than that occurring with FR 50, followed by a high rate maintained until the color change and then by a pause until food delivery. With this second pattern, food followed prolonged exposure to red, during which no responses occurred. Although this alternating sequence of patterns characterized all of the birds under FR 100, it was still more consistent under FR

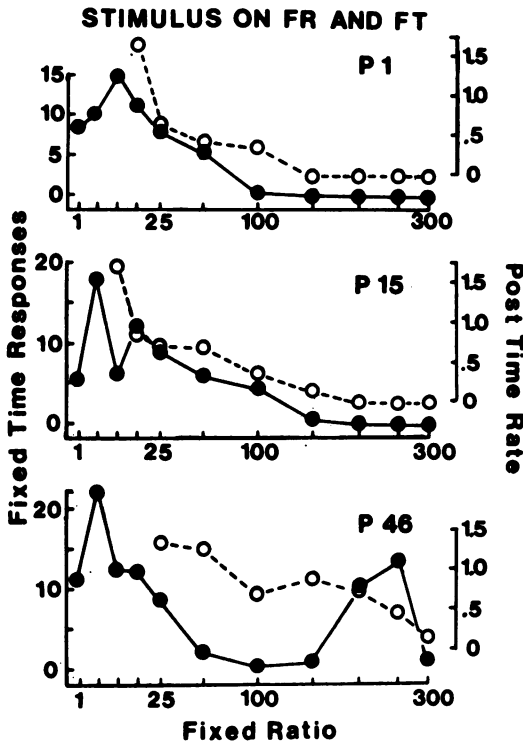


Fig. 5. Mean responses during the FT period and responses per second after the FT period when stimulus changes were correlated with completion of both components. Details as in Figure 3. Scales differ from those of Figure 3.

Table 3

Pause Duration and Interfood (S^B) Time: Stimulus Change on Fixed Ratio and Fixed Time

| | P-1 | | P-15 | | P-46 | |
|--------|-------------|-------------|-------------|-------------|-------------|-------------|
| | Pause (sec) | S^B (sec) | Pause (sec) | S^B (sec) | Pause (sec) | S^B (sec) |
| FR 1 | 8 | 1800 | 0 | 300 | 12 | 600 |
| FR 10 | 43 | 1800 | 2 | 300 | 3 | 600 |
| FR 15 | 42 | 1800 | 143 | 305 | 40 | 600 |
| FR 20 | 1565 | 1812 | 151 | 309 | 173 | 600 |
| FR 25 | 1748 | 1824 | 186 | 322 | 344 | 605 |
| FR 50 | 1766 | 1900 | 253 | 362 | 484 | 635 |
| FR 100 | 1790 | 2057 | 273 | 555 | 565 | 739 |
| FR 150 | a | a | 624 | 1262 | 513 | 765 |
| FR 200 | a | a | a | a | 467 | 832 |
| FR 250 | a | a | a | a | 277 | 1088 |
| FR 300 | a | a | a | a | 683 | 2320 |

*Pause lasted for entire session, and no food presentations occurred.

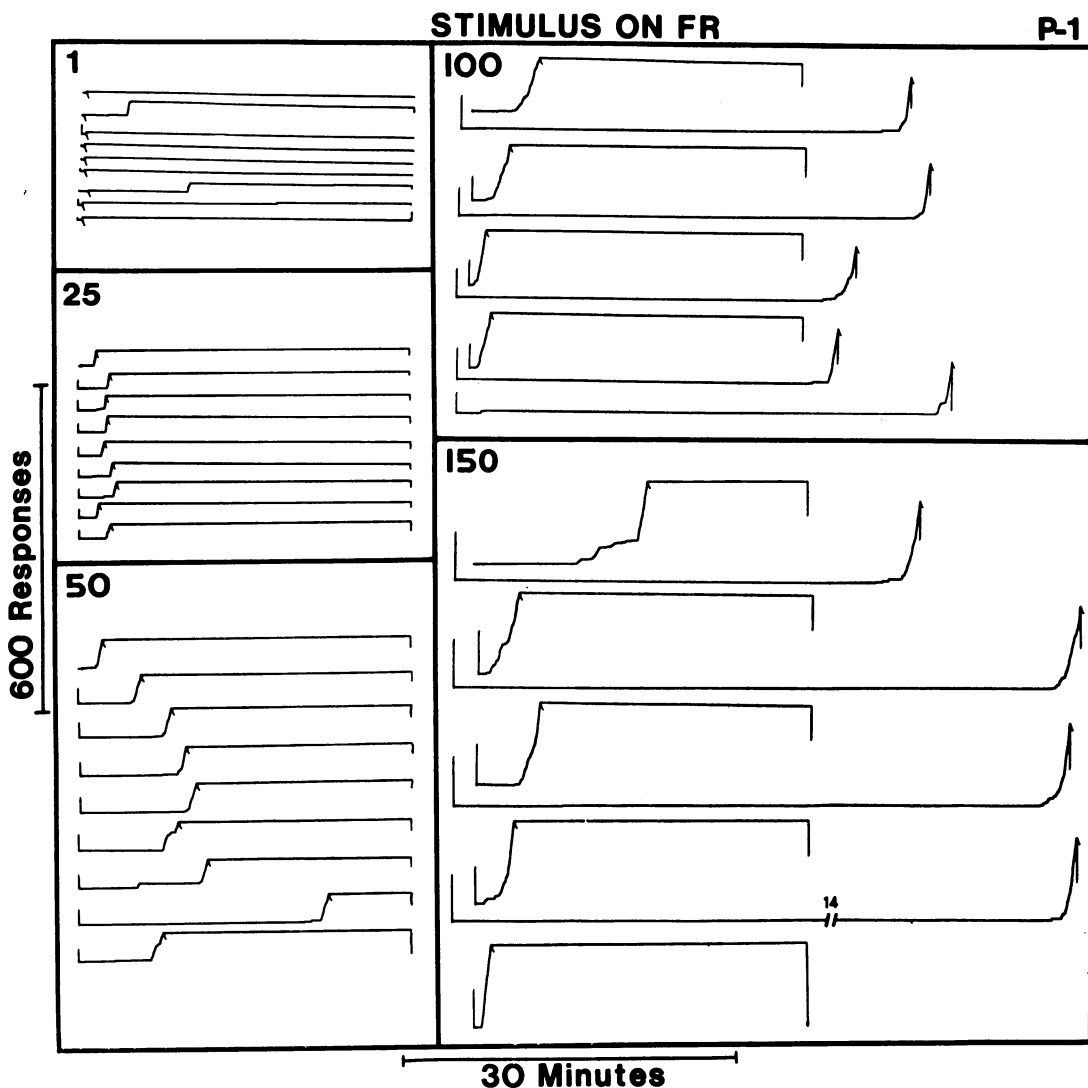


Fig. 6. Cumulative records for P-1 with stimulus changes correlated with completion of the FR component. Successive intervals are arrayed vertically. Details as in Figure 1.

150 for P-1 and P-42. Whereas one food presentation followed a period of not-responding, the next followed a high response rate.

For P-42, the alternation continued at FR 200. With FR 250 and FR 300, long initial pauses were followed by pauses intermediate in the ratio. The FT period always ended before the FR was completed. Bird P-1 stopped responding at FR 200 and P-15 at FR 150.

Figure 2 (open circles) shows the results of runs tests conducted on initial pause duration. More alternations between long and short pauses occurred at FR 100 than expected by chance ($p < 0.05$). In fact, for P-1 the maxi-

imum of 45 runs occurred at both FR 100 and FR 150. (The record shown for FR 100 in Figure 6 was not from one of the last five sessions of the final exposure. It was chosen to illustrate the occasional deviation from alternation at FR 100 in other sessions.) For P-1 and P-15, alternation persisted until responding stopped under the highest ratios. For P-42, alternation eventually was replaced by essentially random deviations around the mean pause under the highest ratios.

Figure 7 shows that mean responses during the FT period first increased and then decreased as the FR was raised, exceeding the FR

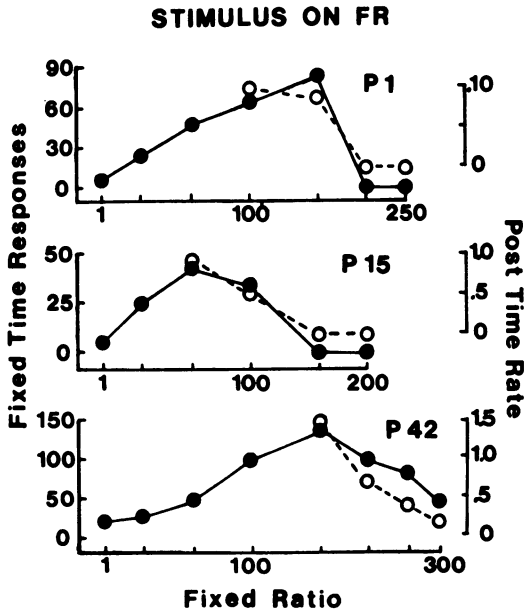


Fig. 7. Mean responses during the FT period and responses per second after the FT period when stimulus change was correlated with completion of the FR. Details as in Figures 3 and 5.

value only at FR 1. Emitted and required responses matched at FR 25 and FR 50, and the pause durations and interfood times shown in Table 4 characterized most intervals. None of the summary means could be representative of individual intervals when patterns alternated. In some, the pause was short, the response requirement was met during the FT period, and food was presented when the FT elapsed. In others, pause durations and interfood intervals were considerably longer than the FT period, and no responses appeared until that period ended. With the highest-valued ratios for P-42, the means again were representative of performance in the individual intervals.

Stimulus Change On Fixed Time

Figure 8 shows cumulative records for P-149 for schedules involving a key-color change from blue to green when the FT period elapsed. With FR 1, no responses usually occurred until the key became green, so that the single response was followed by food presentation. This pattern persisted as the ratio was increased. The records for P-149 under FR 25 and FR 100 were representative of those for all three birds with ratios up to FR 150, and for P-42 up to FR 250.

Table 4
Pause Duration and Interfood (S^R) Time: Stimulus Change on Fixed Ratio

| | P-1 | | P-15 | | P-42 | |
|--------|-------------|-------------|-------------|-------------|-------------|-------------|
| | Pause (sec) | S^R (sec) | Pause (sec) | S^R (sec) | Pause (sec) | S^R (sec) |
| FR 1 | 21 | 1800 | 31 | 300 | 59 | 600 |
| FR 25 | 116 | 1800 | 121 | 300 | 115 | 600 |
| FR 50 | 412 | 1800 | 115 | 308 | 180 | 600 |
| FR 100 | 1013 | 2129 | 192 | 432 | 168 | 600 |
| FR 150 | 1521 | 2501 | a | a | 267 | 609 |
| FR 200 | a | a | a | a | 401 | 748 |
| FR 250 | a | a | | | 693 | 1021 |
| FR 300 | | | | | 776 | 1981 |

*Pause lasted for entire session, and no food presentations occurred.

For P-149, responding increased during the FT period as the ratio was raised to FR 200, FR 250, and FR 300. It then became more erratic at FR 400, 500, 700, and 900. Performance resembled that shown for FR 500: an initial pause of irregular duration was followed by sequences of responses emitted at a high rate. At FR 1100, the pause was consistently lengthened, but the high subsequent response rate continued. Original performance at FR 100, 50, and 25 did not reappear in the descending series of ratios. Now, between 700 and 800 responses were emitted during the FT period, and every food presentation occurred as soon as the FT period elapsed.

Figure 9 and Table 5 summarize the results. Excepting FR 1, where, for P-1 and P-42, responses during the FT period ranged from 0 to 10 and pause durations from 1 sec to the FT value, the means were within 10% of the data for the individual intervals. At ratios higher than FR 150, P-1 stopped responding. At FR 300, P-42 emitted between 20 and 100 responses during the FT period, then paused until the color change, and finally completed the ratio at a high rate. At FR 400, performance again resembled that of FR 250, except that the initial pause lengthened. Different means characterized P-149 in the ascending and descending series of exposures to intermediate and low ratios.

Figure 2 (triangles) shows the results of runs tests conducted on initial pause durations in successive intervals. No tendency for alternation about the mean pause appeared; instead, successive intervals revealed similar pauses. All three birds had instances of fewer runs (alter-

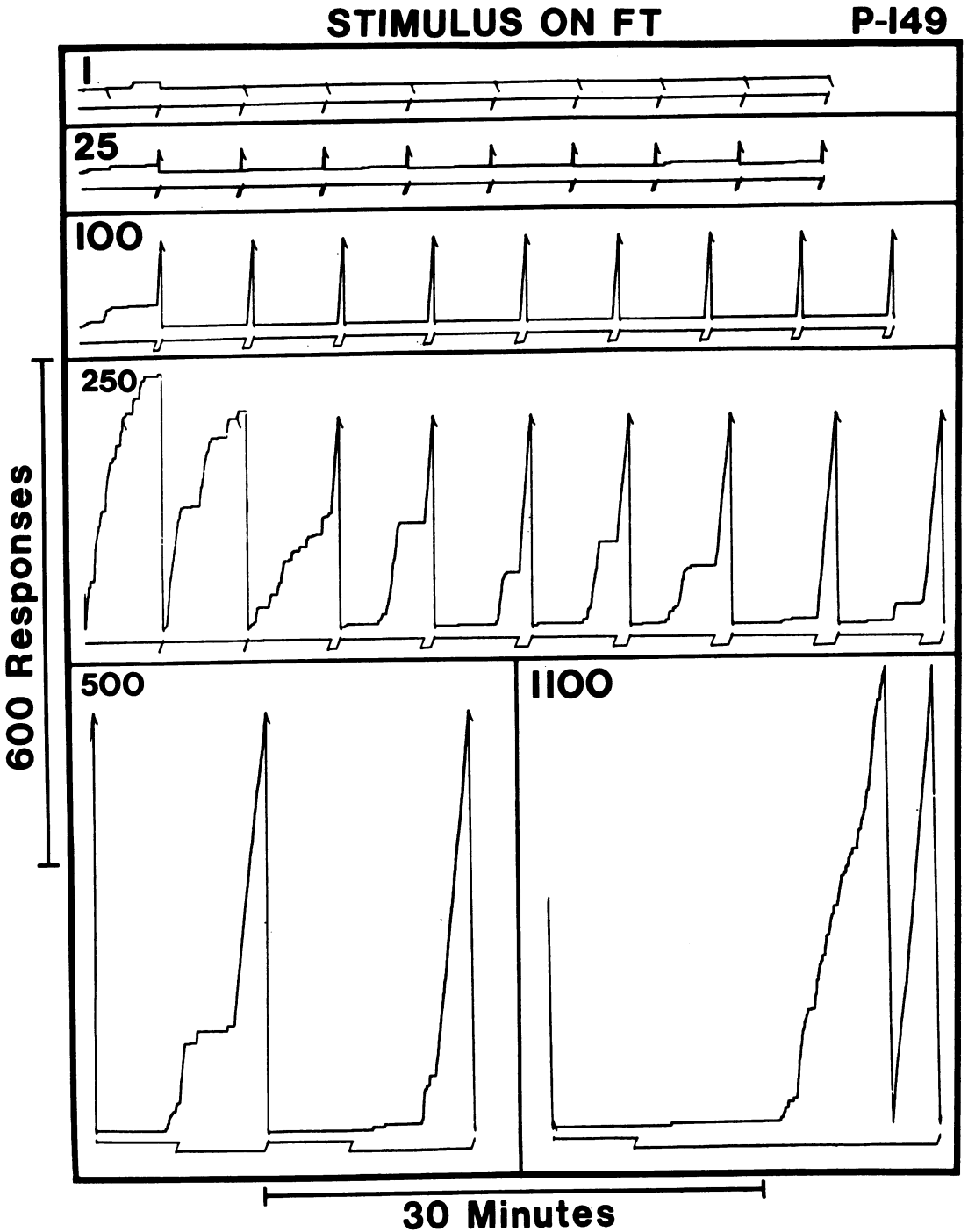


Fig. 8. Cumulative records for P-149 with stimulus changes correlated with completion of the FT component. Details as in Figure 4.

nations) than would be expected by chance ($p < 0.05$). The extreme case for P-1 at FR 10, shown as no runs at all, occurred because every pause matched the mean, perhaps because the

recording apparatus was unable to make sufficiently fine distinctions. In any event, these data corroborate the others in showing that the tendency was for performance to be similar

Table 5

Pause Duration and Interfood (S^R) Time:
Stimulus Change on Fixed Time

| | P-1 | | P-42 | | P-149 ^b | |
|---------|----------------|----------------|----------------|----------------|--------------------|----------------|
| | Pause (sec) | S^R (sec) | Pause (sec) | S^R (sec) | Pause (sec) | S^R (sec) |
| FR 1 | 1154 | 1800 | 189 | 600 | 279 | 300 |
| FR 10 | 1800 | 1810 | 263 | 604 | 141 | 301 |
| FR 25 | 1845 | 1864 | 483 | 615 | 215 | 308 |
| FR 50 | 1898 | 1983 | 543 | 632 | 163 | 312 |
| FR 100 | 1959 | 2133 | 545 | 681 | 272 | 327 |
| FR 150 | 5140 | 6067 | 545 | 726 | 231 | 350 |
| FR 200 | a | a | 627 | 856 | 165 | 341 |
| FR 250 | a | a | 1047 | 2498 | 76 | 341 |
| FR 300 | | | 1224 | 3244 | 175 | 345 |
| FR 400 | | | 2774 | 5047 | 298 | 560 |
| FR 500 | | | | | 159 | 573 |
| FR 700 | | | | | 470 | 2525 |
| FR 900 | | | | | 1260 | 2692 |
| FR 1100 | | | | | 3280 | 4446 |

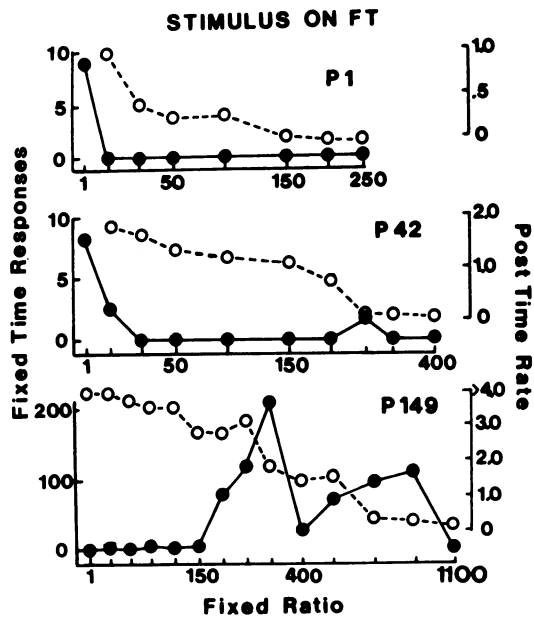


Fig. 9. Mean responses during the FT period and responses per second after the FT period when stimulus change was correlated with completion of the FT. Details as in Figures 3 and 5. Only ratios in the ascending series are included for P-149.

in successive intervals. When variability appeared, it had no obvious relation to performance in preceding intervals.

DISCUSSION

The four conditions revealed a variety of effects. All demonstrated sensitivity to fixed-ratio size, and all suggested that performance did not depend on fixed-time value, at least over the range from 5 to 30 min. Stimuli correlated with completion of one or both requirements controlled both response frequency and the temporal distribution of responses, the precise effects varying with the particular condition and FR value. Stimuli correlated with the FT component or with both the FR and the FT components produced stereotypic effects under all ratios. With either no stimulus changes or a change signalling completion of the FR, whether effects were stereotypic or dynamic depended on the ratio value.

When stimuli followed completion of both the FR and FT components, performance was under stimulus control and was repetitive in successive intervals. At the lowest ratios, responding was usually appropriate to the FR

schedule just after food presentation (when the key was blue) and to the FT component when the change to red signalled that the ratio had been completed. Performance resembled what might be expected to occur with a chained FR FT schedule. With higher ratios, performance was appropriate to the FT schedule during blue and to the FR component after the change to green signalled that the FT period had elapsed. The behavior was like that expected of a chained FT FR schedule. Stimulus function, therefore, interacted with ratio value to determine whether responding did or did not occur during blue.

The shift in pattern might have stemmed from the tendency for longer fixed ratios to produce longer pauses, thereby making it more likely that the FT period would occasionally elapse before the ratio was completed. Once this occurred, responding in the future might be withheld until the stimulus correlated with food presentation appeared. This explanation implies that the same stimulus

^aPause lasted for entire session, and no food presentations occurred.

^bFor P-149, numerals outside parentheses are means for the ascending series of ratios. Numerals inside parentheses are means for the descending series.

control would persist when the ratio later was reduced, but that never occurred. Nor is it clear why dramatic changes should follow a small change in ratio size from FR 10 to FR 15. Thus, although ratio size determined whether responding during blue would or would not be maintained, it is not obvious why the pattern should have changed when it did.

Similar patterns occurred in successive intervals when the stimulus followed completion of the FT component only. For two of the three birds, and for the third in the ascending series of ratios up to FR 200, responses occurred only after the stimulus change signalled the availability of food for responding. The effects were like those of the condition involving stimuli correlated with both the ratio and time requirements, except that pecking only in the stimulus correlated with completion of the FT period occurred with the smallest ratios as well. In the descending series of ratios, one bird was not controlled by the stimulus to any noticeable extent. Barrett (1975) found that in a conjunctive FR FI schedule, two of three pigeons responded mainly after the appearance of a stimulus correlated with the end of the relevant time period, but the third responded earlier. Those data parallel the present ones in showing that a stimulus correlated with time may or may not come to control performance in a conjunctive schedule. In addition, the present results indicate that initially strong control may be lost.

When no stimuli marked completion of either the FR or the FT components, responding first was enhanced and then declined as ratio size increased. The highest average response level occurred at intermediate ratios. This nonmonotonic effect of ratio size with conjunctive FR FT schedules did not resemble Herrnstein and Morse's (1958) results with conjunctive FR FI schedules. They found that responding declined with successive increases in the ratio. The difference originates with the responding established when only one response was required. In Herrnstein and Morse's experiment, the simple FI schedule (one required response) generated maximal responding; in the present experiment, the conjunctive FR 1 FT schedule (one required response) produced few responses (see also Morgan, 1970; Shull, 1970; Staddon and Frank, 1975). Increased responding with small and in-

termediate ratios followed by decreases with high ratios in conjunctive FR FT schedules resemble the effects on overall response rate found in simple FR schedules (Felton and Lyon, 1966; Powell, 1968). Thus, it appears that as ratio size was increased in the conjunctive FR FT, whatever factors operate under simple FR schedules came increasingly into play. The number of responses emitted may have exerted some discriminative control as evidenced by occasional pauses after the ratio requirement had been met (*cf.* Barrett, 1975). The apparent lack of interaction of ratio size with FT duration in determining performance further supports the view that responding was under the control of the ratio component to a considerable extent. Herrnstein and Morse's results, in contrast, reflected not the assumption of control by the FR schedule but rather the ability of simple FI schedules to maintain large amounts of responding and the progressive restriction of this ability by additional response requirements.

Performance tended to be repetitive in successive intervals under the lowest and highest ratios, but the schedule had dynamic effects with intermediate ratios. Long pauses and intervals with reduced responding alternated with short pauses and intervals with responses considerably exceeding the FR requirement. These alternations are not readily attributed to changes in the behavior contiguous with food presentation, because close contiguity between pecking and food delivery was maintained in most intervals. Whether the level of responding was high or low, pecking usually was maintained until food presentation. The source of the cyclicity must lie elsewhere.

Responses may change because the number emitted in one interval actually determines the number emitted subsequently (*cf.* Herrnstein and Morse, 1958; Zeiler, *in press*). The current tendency to respond may reflect the ratio between number of reinforcer presentations and number of responses integrated over an unspecified number of preceding intervals. If this ratio is high (relatively few responses in preceding intervals), the tendency to respond is strong and numerous responses result; if the ratio is low (relatively many responses per reinforcer), the tendency to respond is lessened and fewer responses occur. This hypothesis predicts variability in response number, and it also accounts for the tendency of this vari-

ability to display orderly cyclicities in fixed-interval schedules (Dews, 1970) and in the present conjunctive FR FT schedules. Actually, the present cyclicity assumed a more definite alternation pattern than has occurred with FI schedules, and may therefore more clearly represent the effects of number of responses per reinforcer. The hypothesis also explains decreased responding when the minimum number of responses is restricted by adding an FR requirement to an FI schedule (Barrett, 1975; Herrnstein and Morse, 1958). Such restriction means that the lower limit of the ratio of reinforcers to responses is permanently raised, thereby reducing the tendency to respond.

All of the effects could not stem from the ratio between reinforcers and responses, however. Otherwise, moderate ratios would not have enhanced responding in the present schedules but reduced responding in FI schedules. At this time all that can be said is that restrictions on the ratio between reinforcers and responses appear to decrease responding only when single response requirements establish strong average response tendencies.

Stereotypic and dynamic effects also appeared when a stimulus signalled completion of the FR requirement. At the lower ratios, performance was similar in successive intervals: responses were emitted at a substantial rate until the color change signalled completion of the ratio, and then responding stopped. Responding came under stimulus control and both rate and pattern were repetitive. At the highest ratios, responding also was stereotyped with long pauses followed by irregular rates.

At intermediate ratios, however, the patterns alternated in successive intervals. This dynamic effect of the schedule, although appearing at approximately the same ratios as the one occurring with no stimulus changes, could not have stemmed from number of responses, because the number was constant at the ratio value from one interval to the next. Nor would it stem from changes in interreinforcer time. Responding declines and initial pause duration lengthens as interreinforcer time increases (Catania and Reynolds, 1968; Neuringer and Schneider, 1968), so that long interreinforcer times should be followed by long pauses and short times by short pauses. In the present situation, however, long times were

followed by short pauses and short times by long pauses.

A different factor, response-food contiguity, seems critical instead. The behavior closely contiguous with food delivery in one interval predominated in the early part of the next. When the previous interval ended with a pause (FR completed during the FT period), a long pause began the next interval. When the previous one ended with pecking (FT period elapsed before the FR was completed), pecking occurred early in the next. Stimulus control obviously was involved in determining what behavior would be contiguous with food delivery. Appearance of the stimulus signalling completion of the FR resulted in immediate and total cessation of pecking for the rest of the interval, thereby guaranteeing the correlation of a pause with food presentation whenever the FR was completed before the FT.

The dynamic effects of conjunctive FR FT schedules, then, appeared to stem from number of responses in one case (no stimulus changes) and from response-reinforcer contiguity in another (stimulus change on FR). The first involves the sum of responses over one or more interval, whereas the second involves only the behavior occurring at the moment of reinforcer delivery. These hypothesized controlling relations differ not only in the amount of behavior involved, but also in how they exert their effects. The number of responses correlated with reinforcement in one interval does not tend to reestablish itself in the next interval. Instead, it produces more or less responses, depending on its particular quantitative level. In contrast, response-reinforcer contiguity operates by having the behavior immediately preceding reinforcement in one interval predominate early in the next. Although these two sources of dynamic effects differ, both emphasize the continuous role of the relation between ongoing behavior and reinforcement in determining subsequent behavior.

Schedules have dynamic effects when controlling variables arranged by the schedule generate change. Under other conditions, however, the same variables might be involved in producing repetitive, rather than systematically changing performance. Present knowledge does not permit generalization about what variables can establish dynamic effects and under what conditions they will be manifested. What is evident is that such effects do

occur and that schedules of reinforcement not only establish repetitive behavior but also can produce orderly variation.

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