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CONJUNCTIVE SCHEDULES OF REINFORCEMENT: III. A FIXED-INTERVAL ADJUSTING FIXED-RATIO SCHEDULE[1]

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Key pecking of three pigeons was studied under a conjunctive schedule that specified both a fixed-interval and an adjusting fixed-ratio requirement. The fixed-interval schedule was 6 min for one pigeon and 3 min for the other two. The size of the ratio requirement was determined within each cycle of the fixed interval by the duration of the pause before responding began. The fixed-ratio value was at maximum at the start of each fixed interval and decreased linearly until the first response occurred (adjusting fixed-ratio schedule). A peck produced food when the number of responses remaining on the fixed-ratio schedule was completed and when the fixed interval had elapsed. If no response occurred during the interval, the fixed-ratio requirement decreased to one and a single response after the interval elapsed produced food. The initial value of the adjusting fixed-ratio schedule was studied over a range of 0 to 900. Increases in the adjusting fixed-ratio schedule to about 300 responses increased both pause duration and running response rate and also modified the pattern of responding from that obtained under the fixed-interval schedule. Higher values of the adjusting fixed ratio generally decreased pause duration and running response rate and also disrupted responding. Interreinforcement time under the conjunctive schedule was increased substantially when the adjusting fixed-ratio size exceeded 300 responses.

Key words: conjunctive schedules, adjusting schedules, interlocking schedules, fixed-interval schedules, postreinforcement pause, interreinforcement time, key peck, pigeons

Studies of schedules of reinforcement have usually examined the effects on behavior of contingencies arising under schedules specifying the completion of either a number of responses (ratio schedules) or the occurrence of a response after the passage of a minimal period of time (interval schedules). Interval and ratio schedules can be combined in various ways. Under conjunctive schedules, for example, two schedule requirements must both be completed before the reinforcer is presented. Responding maintained under conjunctive fixed-ratio (FR) fixed-interval (FI) schedules shows a rather characteristic pattern that has two distinctive features (Barrett, 1974, 1975; Herrnstein and Morse, 1958). First, the rate of responding is often highest following a pause early in the interval, with the response rate subsequently decreasing as the interval elapses. Second, the number of responses occurring in the initial portion of the interval, before the rate of responding changes, typically approximates the number specified by the ratio schedule. Both of these features of conjunctive schedule control suggest that reinforcement at the end of the interval exerts a rather profound effect on both the rate and pattern of responding temporally removed from its occurrence.

The present study examined the extent to which behavior occurring early in the interval might be controlled by an adjusting FR contingency added to an FI schedule (a conjunctive FI adjusting FR schedule). This schedule combined properties of each of the schedules shown in Figure 1. These are familiar diagrammatic representations of schedules taken from Morse (1966) and Skinner (1958). Time is on the X-axis and the number of responses on the Y-axis. The upper-left diagram shows an FR schedule under which responding is reinforced after the emission of a fixed number of responses denoted by the horizontal line. Under the FI schedule, depicted to the right of the FR, the first response after a specified period

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of time, t, produces food. In the interlocking FR FI schedule (Berryman and Nevin, 1962), food delivery depends on the occurrence of a number of responses that decreases as a function of the passage of time. Two interlocking schedules are shown having different ratio and interval values. Under the conjunctive FR FI schedule, the reinforcer occurs when responding intersects the area in the upper right-hand portion of the figure. Three different response rates are shown as ways of meeting the conjunctive requirement.

The conjunctive FI adjusting FR schedule, shown at the bottom of Figure 1, was used in the present experiment and combined properties of the other schedules. At the beginning of each cycle of the schedule, both a fixed-ratio and fixed-interval requirement were specified; the ratio requirement decreased linearly as time elapsed and continued to decrease until a response occurred. The first response set the value of the ratio requirement. In Figure 1, the first response occurred at t. A response produced food when the interval elapsed (shown at $2t$) *and* when the number of responses remaining in the ratio was completed (*i.e.*, when the number of responses exceeded the ratio shown at n). If the remaining ratio was completed before the interval elapsed, a single response after the end of the interval ($2t$) was reinforced. However, if the interval elapsed without the ratio being completed, food was delivered on the terminal response (n) of the ratio schedule. When the interval elapsed without a response, a single response then produced food (FI schedule).

The ratio value changed directly as a function of the organism's behavior, with the size of the ratio value dependent on pause duration. A short pause established a high-valued ratio and a lengthy pause a low ratio value.

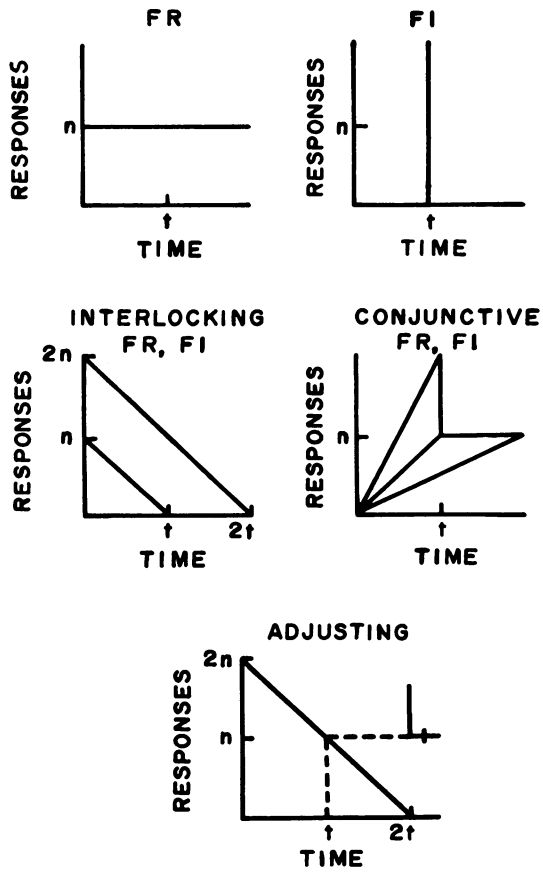

Fig. 1. Diagrams representing various schedules of reinforcement. Under the adjusting schedule, the broken line denotes a response occurrence that intersects a decreasing fixed-ratio requirement and determines the number of responses that must occur before food delivery, which is available at $2t$. The slash on the adjusting diagram parallel to the X-axis above $2t$ denotes that the ratio requirement is variable and depends on the pause duration. A pause duration of $2t$ would result in the FR adjusting to zero and a single response would terminate the FI and produce food. See text for complete description.

METHOD

Subjects

Two pigeons (P-121 and P-9654) with extensive histories under various schedules, and a third bird (P-279) that was experimentally naive at the start of this experiment served. All birds were obtained initially from the Palmetto Pigeon Plant, Sumter, S. C. and were reduced to 80% of their free-feeding weights. Water and grit were continuously available in individual home cages.

Apparatus

Daily sessions (Monday through Friday) were conducted in a single-key pigeon chamber placed inside a sound-attenuating, ventilated enclosure. A response key (R. Gerbrands Co.) was mounted on the center of the front panel 23 cm from the floor and was illuminated by two 7-W green lamps. A peck of at least 15 g (0.15N) operated recording circuits and produced the click of a relay mounted behind the front wall of the chamber. In the center of the front panel 5 cm above the floor was an opening through which mixed grain could be pre-

sented. During the 4 sec of grain presentation, the grain magazine was illuminated and the keylights were darkened. White noise was continuously present in the chamber. Data were collected on counters and cumulative recorders located in a separate room.

Procedure

Key pecking by P-279 was trained by the method of successive approximations. After 60 food presentations under FR 1, the schedule was changed over a five-day period to an FI 3-min schedule. Pecking was then maintained under a 3-min FI schedule (P-279 and P-9654) or a 6-min FI schedule (P-121), *i.e.*, the first response after the FI elapsed produced food. When responding stabilized under the FI schedule, an adjusting FR requirement was added. Under the adjusting schedule, the FR decreased linearly from its initial value as the interval progressed. The first response terminated the decrease in the ratio value and established the minimum number of responses required for a peck to produce food. For example, under the conjunctive FI 6-min adjusting FR 300 schedule, a pause of 3 min established a ratio requirement of 150 responses. If this remaining ratio was completed before the 6-min interval elapsed, a single response at that time produced food; otherwise, food was not presented until the ratio was completed. When the pause lasted for the duration of the FI, the ratio requirement decreased to one and a single response after the interval elapsed produced food. P-121 was studied under four values of this conjunctive FI adjusting FR (180, 300, 450, and 600). P-279 and P-9654 were exposed to seven adjusting FR values (90, 120, 180, 300, 450, 600, and 900).

Table 1 summarizes the sequence of exposure to the various schedule conditions and gives the number of sessions at each condition. Sessions terminated after 30 food presentations or after 3 (P-279, P-9654) or 4 hr (P-121), whichever came first. Schedules were changed when pause duration, response rates, and patterns appeared stable over approximately a two-week period. P-121 and initially P-9654 were returned to the FI schedule between changes in the ratio value of the adjusting FR schedule. P-279 was exposed to successively larger increments in the adjusting FR requirement without interpolated sessions under the FI schedule alone. P-9654 was also trained under the conjunctive schedule where increases in the size of the adjusting FR were made without returning to the FI schedule. These procedural differences had little effect on performance.

Table 1

Sequence of experimental conditions and number of sessions at each condition.

Sessions	*Schedule*
Pigeon P-121	
1- 35	FI 6-min
36-109	Conjunctive FI 6-min adjusting FR 300
110-194	FI 6-min
195-287	Conjunctive FI 6-min adjusting FR 180
288-335	FI 6-min
336-396	Conjunctive FI 6-min adjusting FR 600
397-412	FI 6-min
413-443	Conjunctive FI 6-min adjusting FR 450
Pigeon P-279	
1- 48	FI 3-min
49-120	Conjunctive FI 3-min adjusting FR 90
121-136	Conjunctive FI 3-min adjusting FR 120
137-246	Conjunctive FI 3-min adjusting FR 180
247-277	Conjunctive FI 3-min adjusting FR 300
278-309	Conjunctive FI 3-min adjusting FR 450
310-347	Conjunctive FI 3-min adjusting FR 600
348-382	Conjunctive FI 3-min adjusting FR 900
383-402	FI 3-min
Pigeon 9654	
1- 47	FI 3-min
48- 94	Conjunctive FI 3-min adjusting FR 180
95-125	FI 3-min
125-216	Conjunctive FI 3-min adjusting FR 300
217-253	FI 3-min
254-288	Conjunctive FI 3-min adjusting FR 90
289-307	Conjunctive FI 3-min adjusting FR 120
308-438	Conjunctive FI 3-min adjusting FR 180
439-455	FI 3-min
456-486	Conjunctive FI 3-min adjusting FR 180
496-526	Conjunctive FI 3-min adjusting FR 300
527-599	Conjunctive FI 3-min adjusting FR 450
560-591	Conjunctive FI 3-min adjusting FR 600
592-613	Conjunctive FI 3-min adjusting FR 900
614-645	FI 3-min

RESULTS

Data obtained under the last 10 sessions of each schedule condition were averaged to obtain measures of pause duration (the elapsed time to the first response in each interval), running response rate, and interreinforcement time. These data were based on measures cumulated during each session. Figure 2 shows changes in each of these measures for all birds under the FI schedule alone (FR value of zero) and under all values of the conjunctive FI adjusting FR schedule.

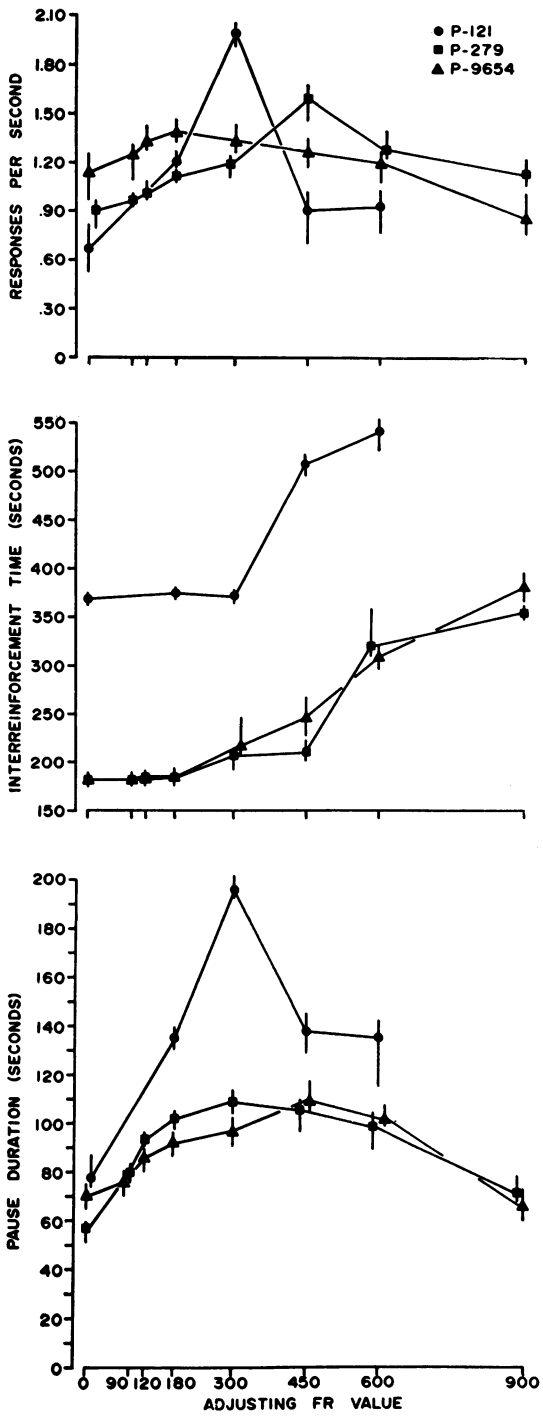

Fig. 2. Effects of the conjunctive FI adjusting FR schedule on pause duration, running response rate, and interreinforcement time. Vertical lines show the range of obtained measures under the FI schedule alone (adjusting FR value = 0) and under various adjusting values of the FR. All points represent means obtained from the last 10 sessions under each schedule condition.

Compared to the FI schedule alone, pause duration, shown in the lower graph of Figure 2, increased for all birds with increases in the size of the adjusting FR schedule from zero to 300 (450 for P-9654) and then decreased from this level at the larger FR values. The middle portion of Figure 2 shows that up to an adjusting FR of 180 (P-279, P-9654) or 300 (P-121), interreinforcement time did not change from that obtained under the FI schedule; beyond these values, the time between reinforcements increased substantially for all pigeons.

Running response rates were obtained by dividing the total number of responses made during each session by the cumulated time from the first response to the response that produced food. The effects of increases in FR size on response rate are presented in the top portion of Figure 2. These changes are generally similar to those of pause duration in showing increases at low to intermediate adjusting FR values, with decreases in running response rate at the higher FR sizes.

Figure 3 shows representative cumulative response records for P-121 under the FI schedule and conjunctive FI adjusting FR schedules. Responding maintained under the FI 6-min schedule (Panel A) was characteristic of that often found with FI schedules, consisting of an initial pause followed by a gradual increase to a higher response rate that was maintained until a response produced food. Cumulative records shown in Panels B and C are representative of performance when the adjusting FR values were 180 and 300 respectively. In these records, the simultaneous displacement of both the response pen and the event pen signifies completion of the adjusting FR requirement. Typically, under the adjusting FR values, the ratio requirement was completed before the 6-min FI had elapsed. The effects of adding the adjusting FR schedule to the FI not only modified the pause duration and rate of responding, but also substantially changed the pattern of responding. Under the adjusting schedules, there was less curvature in the cumulative record and, after the initial pause, responding typically began at a high rate and continued to occur at a relatively constant rate for the remainder of the interval. During some intervals (*e.g.*, Panel B), responding initially occurred at a high rate and then decreased as the interval time elapsed, a pattern comparable to that often seen under con-

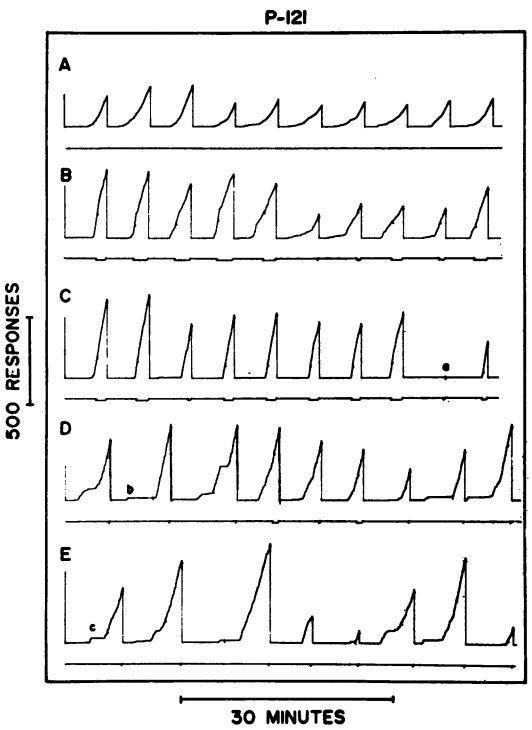

Fig. 3. Cumulative response records for P-121 under the FI 6-min schedule and under the conjunctive FI adjusting FR schedules. Y-axis: cumulative responses; X-axis: time. The response pen reset to the baseline after each food delivery. Completion of the adjusting FR is indicated by a diagonal mark by the response pen and by a simultaneous displacement of the event pen. When the FI elapsed before the adjusting FR requirement was completed, only the response pen was displaced. When no response occurred before the FI terminated and the ratio required decreased to one, the response pen produced a mark and the event pen was offset (*e.g.*, at *a* in Panel C). Panel A: FI 6-min schedule; Panels B-E: conjunctive FI adjusting FR schedules with the FR size of 180 (Panel B); 300 (Panel C); 450 (Panel D), and 600 (Panel E). See text for detailed explanation and description.

junctive FR FI schedules. Of particular interest under the conjunctive FI 6-min adjusting FR 300 schedule (Panel C) were intervals where no responding occurred (*e.g.*, at *a*) and a single response produced food after the FI had elapsed. When the decreasing ratio reached one (at the end of the 6-min interval), the event pen was displaced and a slash occurred on the cumulative record. Typically on those intervals terminated by a single response, only a short period of time elapsed between the end of the interval and the response.

Panels D and E of Figure 3 show performance of P-121 under the conjunctive schedule when the adjusting FR values were 450 and 600 respectively. Despite occasional long pauses, responding was often initiated early in the interval (see *b* and *c*), thereby setting a large remaining ratio requirement. Responding under these adjusting FR values was characterized by many pauses occurring between periods of high rates of responding. Under the 450 and 600 adjusting FR values, the ratio requirement was rarely completed when the interval elapsed.

Figure 4 shows cumulative records for P-279 and for P-9654 under the FI 3-min schedule (top records, Panel A) and under the various conjunctive FI adjusting FR schedules (Panels B-F). Panels B through D show progressively greater increases in pause duration under the conjunctive schedules when the FR value increased from 90 to 300. As with P-121 under the conjunctive 6-min FI adjusting FR schedule, instances of intervals terminated with a single response were also obtained with P-279 and P-9654 (shown at *a*, Panel D under the FR 300 values). Panels E and F of Figure 4 show the disruption in responding with P-279 and P-9654 under the higher-valued adjusting FR 600 and 900 schedules that also occurred with P-121 when the adjusting FR was large. Responding typically occurred early in the interval (*e.g.*, at *b*, Panel E) and, after an initial small number of responses, declined to a lower rate, and then increased. The consequence of responding early in the interval, however, was to establish a large remaining ratio, which had to be completed before food could be delivered. Later in the cycle of each FI, responding increased to a higher rate and was sustained until food delivery occurred (Panel F, at the points labelled *c*).

DISCUSSION

The present experiment examined the effect on responding of adding an adjusting fixed-ratio requirement to an FI schedule. The schedule arranged that, as time during the FI elapsed, the size of the ratio decreased from its initial value until a response occurred and terminated the decrease in ratio size. Food was presented when the remaining ratio was completed and when a response occurred after the FI had elapsed. Under this conjunctive FI adjusting FR schedule, a response early in the cycle of each FI resulted in a larger response

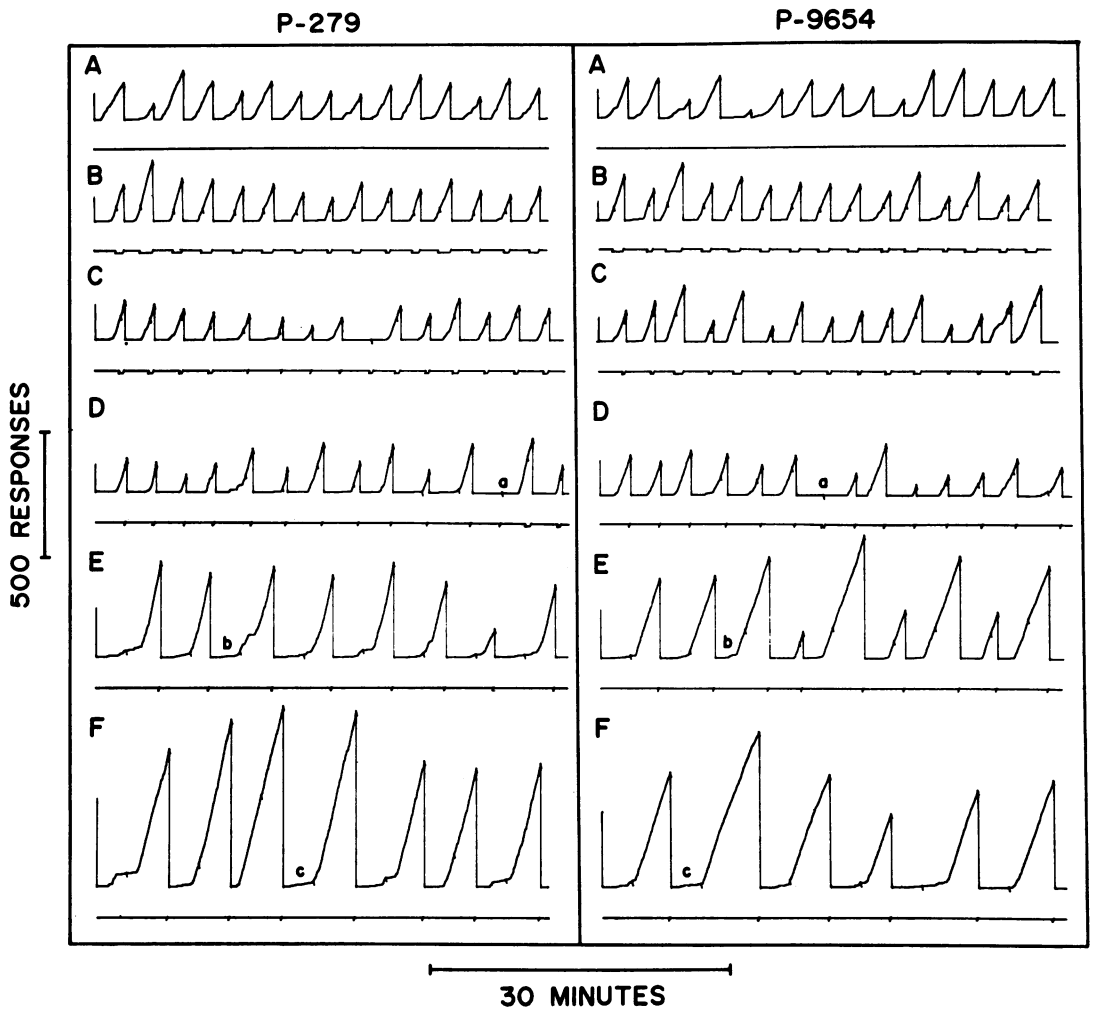

Fig. 4. Cumulative response records for P-279 and P-9654 under the FI 3-min schedule and under the conjunctive FI adjusting FR schedules. Y-axis: cumulative responses; X-axis: time. Details of recording as in Figure 3. Panel A: FI 3-min schedule; Panels B-F adjusting FR schedules of the following sizes: B: 90; C: 180; D: 300; E: 600; F: 900.

requirement than would have existed had responding been initiated later or had not occurred at all. Over a limited range of values, increases in the adjusting FR also increased pause duration from that obtained under the FI schedule alone. However, pause duration did not continue to increase with progressively higher adjusting FR values but, instead, decreased beyond adjusting FR values of approximately 300. Responding maintained under this conjunctive schedule at the higher-valued adjusting FR sizes showed characteristics of strained performance often seen under large FR schedules (*cf.* Ferster and Skinner, 1957).

The conjunctive FI adjusting FR schedule did not increase interreinforcement time at lower FR values, although it did lengthen pause duration. These results indicate that, within certain limits, pause duration can be systematically manipulated without affecting interreinforcement time. Although pause duration has typically been found to be relatively insensitive to variables other than interreinforcement time under FI schedules (Elsmore, 1971; Neuringer and Schneider, 1968; Shull, 1970, 1971), the present experiment suggests a means of modifying pause duration independent of the time between delivery of reinforcements.

The present results are also relevant to an understanding of control engendered by conjunctive schedules. In this experiment, as in previous studies of conjunctive schedules (Barrett, 1974; 1975; Herrnstein and Morse, 1958; Powers, 1968), both FR and FI requirements were specified. In contrast to the results of those studies, however, the conjunctive pattern of responding was usually absent in the present experiment. This pattern typically consists of a pause terminated by an initial high response rate that is followed, in turn, by a lower rate of responding until food delivery. Unlike previous work, the ratio value in the present experiment was not fixed. Instead, it varied as a function of pause duration. Herrnstein and Morse (1958) suggested that after an extended history of conjunctive FR FI, the FR value becomes a discriminative stimulus. This outcome results from repeated instances when the interval has elapsed without a prior response and food is then delivered when the ratio schedule is completed. The fact that the ratio value in the present experiment adjusted with pause duration probably accounts for the departure from the conjunctive FI FR response pattern described by Herrnstein and Morse (1958). Unless pause duration was invariant from interval to interval, the ratio value was constantly changing, a factor that could preclude the development of precise discriminative control. The conjunctive FI adjusting FR schedule did, however, generate a pattern of responding where the number of responses comprising the initial period of high-rate responding varied from cycle to cycle. Although all pigeons showed instances where this pattern occurred, responding by P-121 typified patterns that would probably be obtained under a conjunctive schedule specifying both an FI and variable-ratio schedule.

Behaviors occurring early in an interval appear to be remarkably sensitive to the presentation of the temporally distant reinforcing event terminating that interval. This same point was made by Morse and Herrnstein (1956) in studying responding maintained under a tandem FR DRL schedule: "It is clear that the animal responds to contingencies that are remote from reinforcement . . . the effect of these remote contingencies is to produce a complex but highly consistent pattern of responding (p. 312)." The systematic control of pausing early in the FI by the ratio contingency in the present experiment strongly supports this view.

Combinations of schedules can be used to intensify and differentially control selected aspects of behavior. With few exceptions (*e.g.*, Ferster and Skinner, 1957; Kelleher, Fry, and Cook, 1964; Randolph, 1972; Randolph and Sewell, 1968), adjusting schedules have not often been investigated. Nevertheless, they seem to offer great potential for an understanding of complex contingencies of reinforcement and may be of substantial benefit in the manipulation of relevant controlling variables. The latter may be particularly helpful in experiments where interreinforcement time has been shown effectively to determine the frequency of occurrence of behavior such as schedule-induced drinking (Falk, 1971) and schedule-induced attack (Flory, 1969). Since the majority of these behaviors occur during the pause, and since pause duration has typically been related to the time between reinforcements, it is possible that the direct control of pause duration without affecting interreinforcement time may allow for manipulation of the extent to which such schedule-induced behaviors occur.

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