

*LATENCY AND FREQUENCY OF RESPONDING UNDER  
DISCRETE-TRIAL FIXED-INTERVAL  
SCHEDULES OF REINFORCEMENT<sup>1</sup>*

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Pigeons' key pecking was studied under a number of discrete-trial fixed-interval schedules of food reinforcement. Discrete trials were presented by briefly illuminating the keylight repetitively throughout the interreinforcement interval. A response latency counterpart to the fixed-interval scallop was found, latency showing a gradual, negatively accelerated decrease across the interval. This latency pattern was largely invariant across changes in fixed-interval length, number of trials per interval, and maximum trial duration. Frequency of responding during early trials in the intervals varied, however, with different schedule parameters, being directly related to fixed-interval length, inversely related to number of trials, and complexly affected by conjoint variations of fixed-interval length and number of trials. Response latency thus was found to be simply related to elapsed time during the interval while response frequency was complexly determined by other factors as well.

Response latency, the elapsed time between a change in some external event and a response, has received relatively little use as a dependent variable in studies of reinforcement schedule effects. Skinner (1950) first objected to its use as a measure of operant behavior, preferring a measure less explicitly tied to external antecedent stimuli (*i.e.*, free-operant rate of responding). Since rate of responding may be a measure complexly determined by many variables other than those explicitly specified by a schedule of reinforcement, such as control by the preceding response and "adventitious" reinforcement contingencies, it seems important to sample other measures of the behavioral effects of schedules of reinforcement. The present experiment demonstrates control of response latency and response frequency by a discrete-trial analogue of the fixed-interval (FI) schedule of reinforcement.

Response latency has previously been found

to vary with the schedule of reinforcement. The studies, however, are few. Zimmerman (1960), for example, used a discrete-trial procedure to train rats to emit lever presses only in the presence of a light. Changing the schedule of reinforcement for correct responses from continuous reinforcement (CRF) to a variable-ratio 3 (VR 3) produced increased length and variability in response latencies to the light onset. Similar results were obtained by Stebbins and Lanson (1962) in a reaction-time procedure with rats. Further, response latency has been shown to vary during the interreinforcement interval of an FI schedule of reinforcement. Wall (1965) employed a discrete-trial procedure to examine bar-press latencies of rats at different points in time during the interreinforcement intervals of an FI 1-min schedule of reinforcement. A retractable lever was presented either early, midway, or late in the interreinforcement interval. A second lever presentation occurred at the end of the interval, and a press at this time was reinforced. Thus, response latencies were obtained for the reinforced lever press and one other lever press occurring at one of the other temporal locations in each interreinforcement interval. Mean response latencies were shortest for reinforced lever presses, and were longer for non-reinforced lever presses occurring earlier in the interval. However, since only one non-reinforced trial was presented in each interval, and only three temporal locations in the interval were utilized, it is not possible to assess care-

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fully changes in response latency during the interreinforcement interval.

Schneider and Neuringer (1972) presented a more complete mapping of response latency patterns during FI schedules of reinforcement. Pigeons were trained on a discrete-trial procedure in which a sequence of equally spaced, brief key-illumination periods were presented during the fixed interval. The first response to the lighted key following the end of the interval produced access to food. While response latencies were longer earlier in the interval, two types of latency patterns were observed: either a gradual shortening of latency across the interval, or a sudden shift from consistently long latencies to consistently short latencies (a "break-run" or two-state performance). These authors, however, present only transformed data. Assuming a two-state performance, they presented latencies averaged across trials in particular ordinal positions preceding and following the estimated "break-point" for each interval. From these data one cannot assess changes in response latency obtained for various trial positions within the interreinforcement interval. It is thus impossible to compare their data with the wealth of free-operant FI data analyzed in the standard manner. Further, Schneider and Neuringer presented trials at a fixed rate, so changes in response latency and response frequency across varied FI lengths were confounded by the simultaneous manipulation of two variables, number of trials per reinforcement and interreinforcement interval.

The detailed characteristics of performances generated by discrete-trial FI schedules of reinforcement were studied in the present work. Some general characteristics of performances under these schedules were examined, including response latency changes during acquisition and the pattern of changes in response latency within individual interreinforcement intervals. Also, changes in response latency and in response frequency are shown as a function of the following parameters of the schedule: (1) the length of the fixed interval, (2) the minimum number of trials occurring per interval, and (3) the duration of each trial.

## METHOD

### *Subjects*

Five male White Carneaux pigeons were maintained at 75% of their free-feeding

weights. Two of the birds, B135 and B161, had previous histories of exposure to variable-interval schedules of reinforcement. The other subjects were experimentally naive.

### *Apparatus*

A modified Grason-Stadler sound-attenuation chamber, equipped with a blower for ventilation, was kept in a darkened room in which white noise was continuously present. A translucent Gerbands pigeon key was mounted behind a circular opening, 1.9 cm in diameter, located 21.6 cm above the floor, and 8.9 cm to the right of center of the black intelligence panel. The key was transilluminated by a 28-V lamp (# 1820). The force required to operate the response key was 8 g (0.08 N), and each operation of the key produced a relay click that was clearly audible over the white noise. A Lehigh Valley pigeon feeder delivered mixed grain reinforcement through an opening 6.35 cm above the floor in the center of the intelligence panel. Dim, indirect illumination of the chamber was produced by a small houselight, centrally mounted on the top rear wall, facing upwards. Electro-mechanical scheduling and recording equipment were located in an adjacent room. Human observers near the animal chamber could not hear the operation of this equipment.

### *Procedure. The Basic Schedule*

The schedule was similar to the discrete-trial FI schedule described by Schneider and Neuringer (1972). The first response during a "trial" (see below) that occurred following a fixed length of time since the last reinforcement produced illumination of the feeder opening and access to grain for 3.5 sec. Discrete trials were superimposed on this schedule by breaking each interreinforcement interval into a number of keylight-on-keylight-off cycles of fixed duration. The keylight-on segment of each cycle is referred to as the "trial", and the keylight-off segment as the intertrial interval (ITI). In the absence of responding, trials were 1.75 sec long. The first response during a trial darkened the key and produced the ITI for the remainder of that cycle. Responses during ITIs normally had no scheduled consequences (see, however, Delay procedure). The lengths of light-on and ITI periods could vary, depending on responding; however, the time between successive trial onsets (*i.e.*, cycle

length) was constant over trials. If a subject failed to respond during the trial coincident with the end of the FI, additional cycles followed until the reinforcer was obtained. This resulted in a fixed minimum but a variable maximum number of trials during each interval, depending on performance. The first cycle of an interval, initiated at the end of reinforcement, contained no trial segment. Thus, one cycle length of time separated the end of reinforcement from the first keylight-on period in an interval. The houselight was illuminated whenever the keylight was off and was turned off with keylight onset. Both the keylight and houselight were off during reinforcement. Figure 1 diagrams these various relationships under a discrete-trial fixed-interval schedule in which a minimum of six trials occur per reinforcement.

To facilitate description of the experimental conditions, schedules will be specified in terms of the interreinforcement time (T) and the minimum number of trials (N) that could occur during each interval. This is written as FI T (N). Specification of these two parameters also specifies the cycle lengths in a schedule (T/N). (Since no trial occurs during the first cycle of an interval, N complete cycles will have occurred by the Nth trial onset.) For example, an FI 3-min (15) schedule with 1.75-sec trial durations specifies the following: (1) the reinforcer was produced by the first trial response that occurred at least 3 min after the last reinforcer, (2) the reinforcer became available at the beginning of the fifteenth trial, (3) the cycle length was  $180/15 = 12$  sec, and (4)

the minimum time in each ITI was  $12.0 - 1.75 = 10.25$  sec.

*Initial training.* The three naive birds, B419, B522, and B523, were magazine trained and then pecking the response key was hand-shaped. During these sessions the response key was illuminated for 10-sec periods, alternating with 1-sec periods during which the key was dark. Once the pecking response was acquired, each key peck was reinforced if it occurred during the keylight-on periods. Responses during keylight-off periods had no scheduled consequences. It was hoped that this procedure would reduce pecking on the dark key. No special training was required to establish pecking in the experienced birds.

*Experimental conditions.* Following the initial shaping procedure, B419, B522, and B523 were placed on a discrete-trial FI 12-sec (1) schedule of reinforcement followed by exposure to FI 2-min (10). The FI 12-sec (1) schedule is a discrete-trial analogue of the CRF schedule of free-operant situations, since every response on the lighted key is reinforced. The transition from a discrete-trial CRF schedule to a discrete-trial FI schedule is thus shown for these subjects. Birds B419 and B522 were then used in a related experiment (not reported here) in which they were exposed to a slightly modified discrete-trial procedure. B419 was then stabilized on a discrete-trial FI 3-min (15) schedule of reinforcement, and B522 was stabilized on a discrete-trial FI 5-min (25) schedule of reinforcement. Maximum trial durations were then increased from 1.75 sec to 5.0 sec, and finally to 10.0 sec; all other schedule

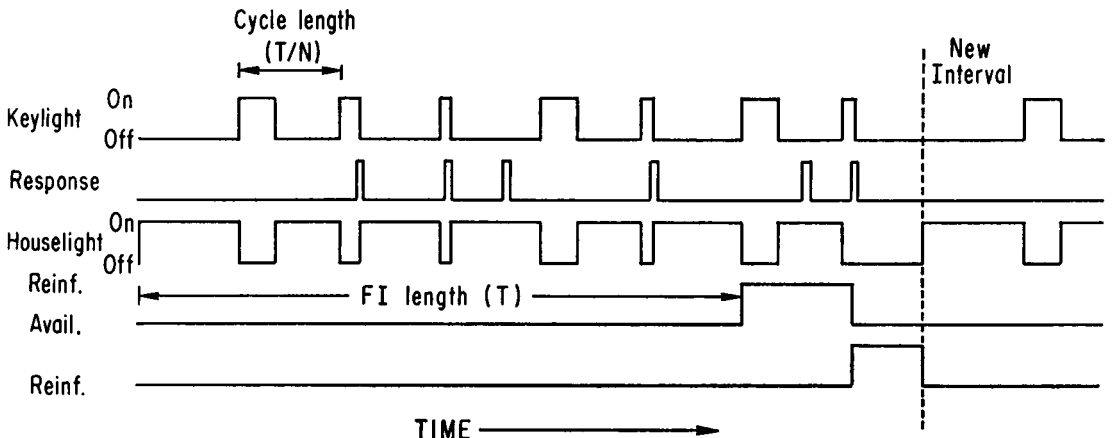


Fig. 1. Diagram of relations between keylight, responding, houselight, reinforcement availability, and reinforcement under the present discrete-trial FI schedules of reinforcement.

parameters were held constant. The number of sessions and the number of reinforcements per session under these conditions are given in Table 1. Birds B135 and B161 were exposed to a variety of discrete-trial FI schedules of reinforcement. The sequence of schedules, number of sessions, and number of reinforcements per session are given in Table 1. FI lengths ranged from 15 sec to 5 min, and the number of trials (N) ranged from one to 20. Trial durations under all schedules were 1.75 sec for these two birds. For all subjects, sessions were terminated after a fixed number of reinforcements were delivered (see Table 1).

*Delay procedure.* During exposure to some of the discrete-trial FI schedules of reinforcement, B161 responded frequently during ITI periods. It would occasionally be responding when a trial started, producing unusually short response latencies unrelated to trial onset. To eliminate this ITI responding, a delay contingency was added requiring that a 5-sec response-free period precede the onset of each trial. This delay contingency was also em-

ployed for other subjects during the early experimental conditions to minimize the adventitious reinforcement of such responding. The delay contingency was maintained for subjects until ITI responding either stopped or stabilized at some minimal level. The delay procedure was discontinued for a minimum of 10 sessions before an experimental condition was terminated. The subjects and conditions during which the delay contingency was used are noted in Table 1. Data for analysis were taken from the last five of these 10 post-delay sessions, except for the acquisition data of B419, B522, and B523, which were taken while the delay contingency was still being used. Responding during ITI periods for these subjects was infrequent at this time, and variations in the temporal characteristics of the schedule were minimal.

Subject B161 had high levels of ITI responding after long exposures to the delay contingency during early conditions, and was thereafter exposed to the delay only infrequently, as noted in Table 1. The data of B161 indicate the effects of frequent ITI responding on response latency and response frequency.

*Data analysis and recording.* Individual response latencies to trial onsets were collected by pulsing a printout counter (Moduprint B, Presin Co) at a rate of 28.6 pulses per second during the time between a trial onset and either the next response or the end of the trial. This pulse rate produced latencies coded in 35-msec bandwidths. A second channel of the counter marked whether or not a response occurred during that trial; a third channel indicated reinforcement delivery. The latencies during the last five sessions under a condition were subsequently transferred to IBM cards for later computer analysis. Latencies collected before the first reinforcement of each session were excluded from this analysis. Response latencies to trial onsets were grouped according to the position of the trial within an inter-reinforcement interval. For example, all latencies that occurred to the first trial after a reinforcement were pooled, and so on. A latency distribution was then constructed for each trial position, and a median and interquartile range (Q) were determined for each distribution. Since distributions are normally positively skewed, the median was employed as the measure of central tendency. It should be noted that the term "response latency" is ap-

Table 1  
Experimental Conditions

Subjects	# Sessions	# Trials	FI Length	Trial Duration	Rft/Session
B135 & B161	20	1	15 sec*	1.75 sec	100
	10	2	30 sec	"	100
	12	4	1 min	"	50
	24	8	2 min	"	20
	16	12	2 min	"	20
	20	15	1 min	"	50
	20	15	5 min	"	20
	28	15	2 min	"	20
	20	20	2 min	"	20
	35/45	15	3 min*	"	20
B135 only	20	12	3 min*	"	20
	20	20	5 min	"	20
B419	6	1	12 sec*	1.75 sec	20
	10	10	2 min*	"	20
	21	15	3 min	"	10
	16	15	3 min	5.0 sec	10
	21	15	3 min	10.0 sec	10
B522	6	1	12 sec*	1.75 sec	20
	10	10	2 min*	"	20
	29	25	5 min	"	10
	17	25	5 min	5.0 sec	10
	14	25	5 min	10.0 sec	10
B523	6	1	12 sec*	1.75 sec	20
	10	10	2 min*	"	20

(\*denotes delay procedure)

plied only to the elapsed time between a trial onset and a response during that trial. If a subject failed to respond during a trial, no latency was assigned to that trial, and the trial was excluded from the latency analysis. These response failures are reflected in the other behavioral measure employed, response frequency (the number of trials at a given trial position containing a response divided by the total number of trials presented at that position). In order to compare the time course of changes in response latency and response frequency during the interreinforcement intervals under different-valued FI schedules, these measures were plotted as a function of the proportion of time elapsed during an interval and termed "relative time". The occasional omission of data points in the median latency graphs indicates that too few responses ( $N < 10$ ) occurred at those points to permit reliable determination of a median.

Response latencies were also cumulated as a function of time during sessions to produce "cumulative response latency" curves in the following manner: at the onset of a trial, the stepping switch of a cumulative recorder (Gerbrands, Model C-3) was stepped at a rate of 15 steps per second until a single response or termination of a trial occurred. The upward excursion of the pen was thus proportional to the response latency of each trial. Each successive response latency produced additional upward excursions of the pen, thus cumulating response latencies during each interreinforcement interval. The paper drive operated continuously during sessions, while pen resets occurred after each reinforcement. Trial responses were indicated by an event pen.

## RESULTS

The acquisition of performances under a discrete-trial FI 2-min (10) schedule of reinforcement is shown in Figure 2 for B522 and B523. These birds were previously performing under a FI 12-sec (1) schedule, and had not been exposed to an intermittent discrete-trial schedule of reinforcement before this time. As seen in Figure 2, the cumulative response latency curves of both subjects were highly variable on Day 1. One notable pattern, especially for B522, was a positive acceleration in cumulative latency. This pattern resulted most frequently from frequent responding during

trials immediately after reinforcement and infrequent responding during later trials. In a few intervals, this pattern was maintained even though responses occurred in all trials, thus indicating a lengthening of latency over time during these intervals. By Day 10, two patterns of response latency changes had emerged. The first, shown frequently by B523, was an inverted scallop-like pattern, indicating a gradual shortening of latency as reinforcement approached. The second pattern, only occasionally seen in these records, was a break-run pattern in which the latency curves showed an absence of responding for the first few trials followed by the occurrence of roughly equal response latencies for the remainder of the interval. Performances on days intermediate to the two days shown in Figure 2 were characterized by various mixtures of the response latency patterns of Days 1 and 10.

The pattern of occurrence of trial responses on Day 1, indicated by downward movements of the event pen in Figure 2, was typically one in which responding occurred early in the intervals, but became more infrequent during later trials. By Day 10, this pattern had reversed, with trial responding more frequent in the later parts of the intervals. Trial responding also frequently occurred in runs, with only an occasional break in these runs after responding had started.

As an example of stable performances under discrete-trial schedules, cumulative response latency curves generated under schedules of FI 2-min (20), FI 3-min (15), and FI 5-min (20) are shown in Figure 3 for B135. Each record is from the final session of a condition. Since independent variations of T and N produce different rates of change in the slopes of these curves, an inset precedes each record showing the maximum slope that may occur under that schedule (*i.e.*, the slope obtained in the absence of responding). The inverted scallop-like pattern is most easily seen under the FI 5-min (20) schedule of reinforcement, though it also occurred occasionally under the other two schedules of reinforcement. The break-run pattern of latency changes predominated under the FI 2-min (20) and FI 3-min (15) schedules of reinforcement. This latter pattern was mainly one in which response latencies maintained one value for a period of time, followed by a shift to a different, usually shorter, latency for the remainder of an interval. A common

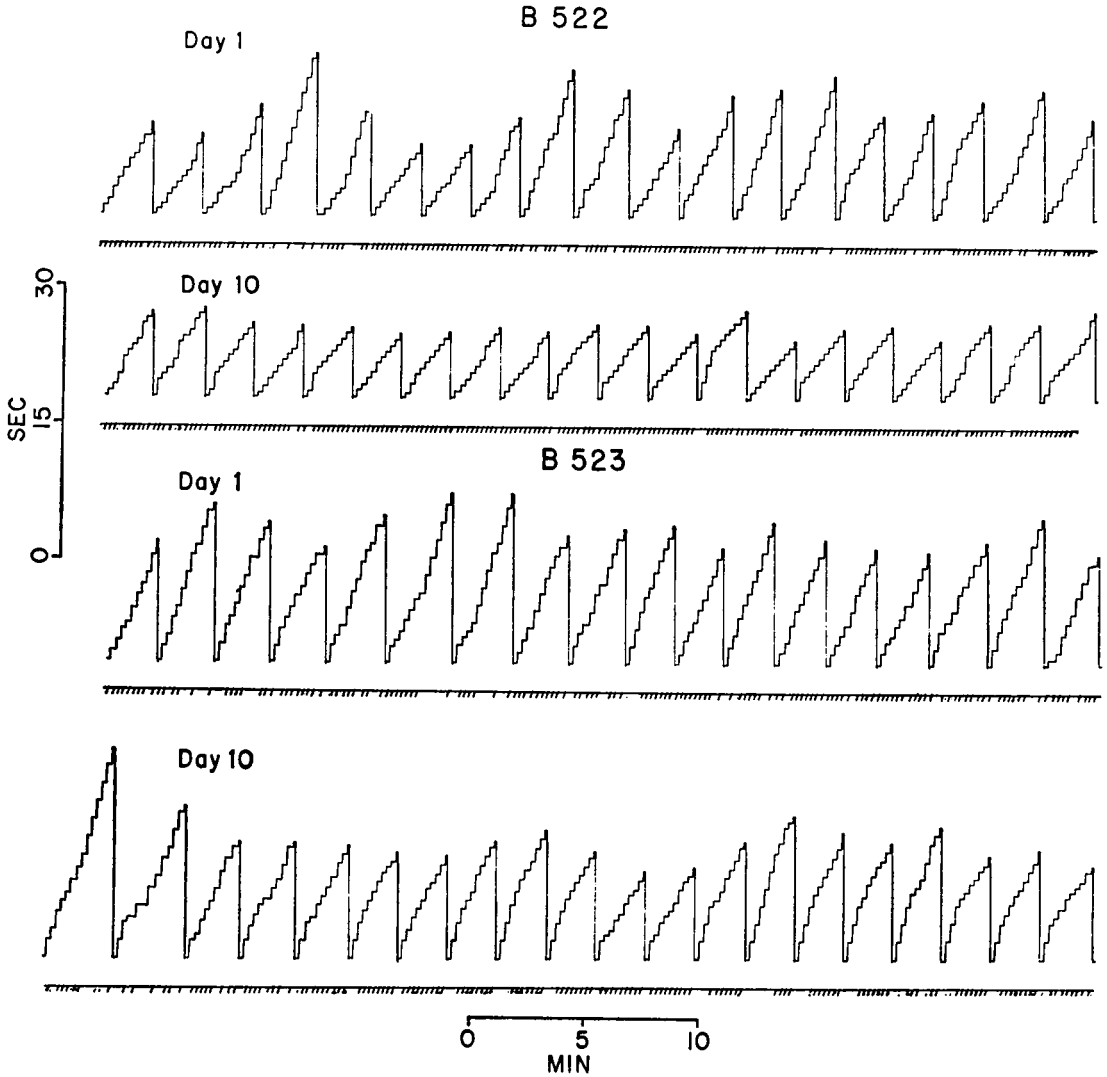


Fig. 2. Cumulative response latency curves for B522 and B523 showing performances on Days 1 and 10 following a change in the schedule of reinforcement from FI 12-sec (1) to FI 2-min (10). Each record shows a complete session. See text for details of recording technique.

variation of this pattern was one in which an initial no-response segment was followed by a shift to relatively short response latencies for the remainder of the interval.

The pattern of trial responding for B135 was similar to those previously noted for B522 and B523. Responding was usually absent for the first few trials after reinforcement, followed by a normally unbroken run of trial responses through the next reinforcement.

An example of the distribution of response latencies at various trial positions is given in Figure 4 for B135 and B161 under two discrete-

trial schedules, FI 1-min (4) and FI 2-min (8). Considering the data for B135 first, latency distributions were normally positively skewed, and frequently bimodal, with primary and secondary peaks of 0.5 and 0.9 sec, respectively. Distribution medians tended to be lowest at trial positions closest to reinforcement, while the highest medians occurred at the first trial position in an interval. The transitions between these early occurring high medians and the late occurring low medians were of two types: (1) a very rapid or immediate transition from high to low median latencies, as exempli-

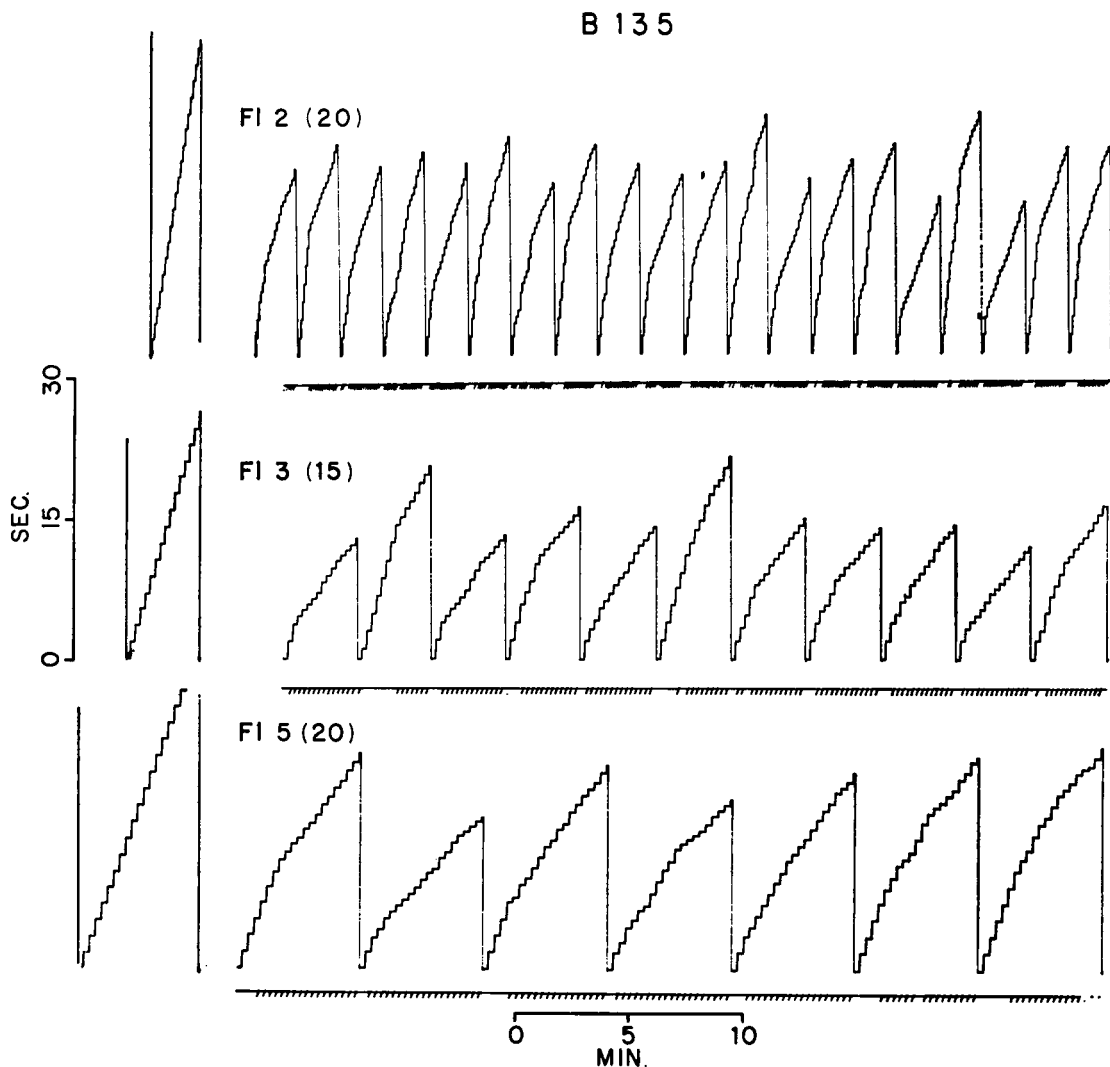


Fig. 3. Cumulative response latency curves for B135 under FI 2-min (20), FI 3-min (15), and FI 5-min (20) schedules of reinforcement.

ified by the distributions of B135 under FI 1-min (4), or (2) a slower, more gradual change in median latency, seen under the FI 2-min (8) schedule for B135.

As demonstrated in Figure 4, the data of B161 exhibit some of the same general characteristics as those of B135. For example, latency distributions for B161 were also positively skewed, and sometimes were bimodal [*e.g.*, under FI 2-min (8)]. Distribution medians also decreased under the FI 1-min (4) schedule as reinforcement approached. However, as previously noted, B161 emitted ITI responses with great frequency (*e.g.*, 200 to 300 ITI responses per session under the conditions in Figure 4),

while B135 rarely emitted ITI responses. This performance difference of B161 can be seen in (1) the increased frequency of short-latency responses ( $<0.4$  sec) in Figure 4; (2) the greater frequency of short-latency responses during the later trials, which was correlated with an increased frequency of ITI responding through individual interreinforcement intervals; (3) the greater variability in the latency distributions, especially at the later trial positions, and (4) the presence of multiple peaks in the latency distributions. These differences indicate a relative lack of control of responding by the keylight for B161, as compared to that of B135.

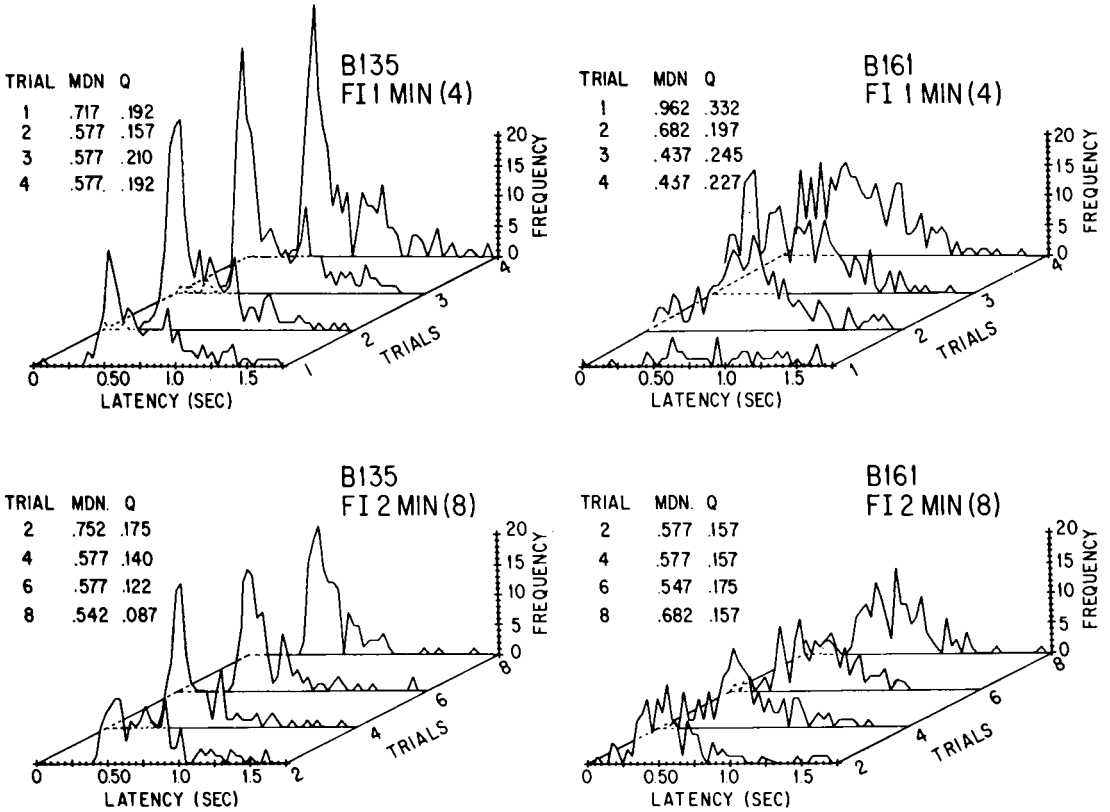


Fig. 4. Frequency distributions of response latencies at successive trial positions for B135 and B161 under FI 1-min (4) and FI 2-min (8) schedules of reinforcement. Reinforcement became available at the end of the last trial.

*Manipulation of N and T.* The data for B135 and B161 are presented in three sections. The first section presents data for those procedures that varied only in FI length (the minimum number of trials per interval,  $N$ , was held constant at 15). The second section presents data for procedures varying in  $N$  (FI length held constant at 2 min). The third section presents data obtained from conjoint variation of both FI length and  $N$  (cycle length was constant at 15 sec), a manipulation comparable to that made by Schneider and Neuringer (1972). Data are presented first for response latency in Figure 5 and then for response frequency in Figure 6. Median latencies of the last five sessions are given in Figure 5.  $Q$  values for median latencies are also presented (the unconnected points in Figure 5).

#### Response Latency

*Variations in FI length ( $N = 15$ ).* For both B135 and B161, median latencies were generally maximal at the start of the intervals, and

decreased rapidly thereafter (Figure 5, top panels). The decline in latency was orderly for B135 and was comparable across different FI lengths except for shorter median latencies throughout the FI 1-min interval. The variability of latencies for B135 followed the same general trend as median latency, maximal during the first trials of an interval and decreasing thereafter. The decline in latency was less orderly for B161. Median latency curves for this subject separated according to FI length after the first two trials, with longer latencies occurring under long FI lengths. For the FI 5-min length, latencies were roughly constant throughout the interval. Overall variability in latency was considerably greater for B161. While variability was slightly higher during the first trial, there were no consistent changes in variability thereafter for B161.

The changes in latency observed for B161 were correlated with changes observed in ITI responding over the same conditions. Intertrial interval response rates for B161 were inversely



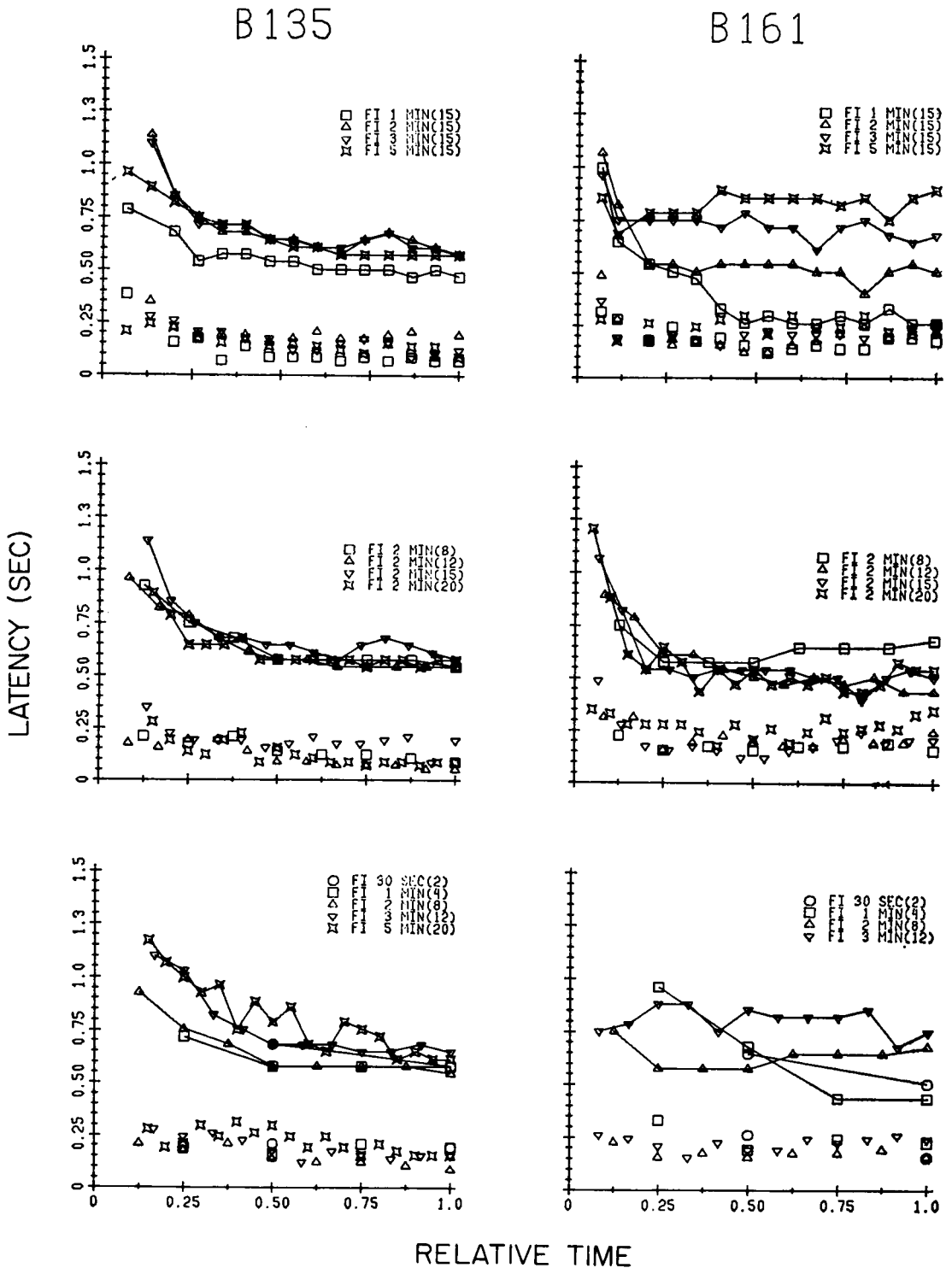


Fig. 5. Median response latency curves for B135 and B161 under all experimental conditions. Unconnected symbols plot the semi-interquartile ranges (Q values) for the associated medians.

related to FI length: 32.5, 5.0, 2.25, and 1.70 responses per minute for FI lengths of 1, 2, 3, and 5 min, respectively. Further, sample distributions of ITI responding during the interreinforcement intervals of the FI 1-min and 5-min schedules showed that local rates of ITI responding increased as time for reinforcement approached under the FI 1-min; local rates of responding under the FI 5-min, however, were relatively flat across the interreinforcement interval. Response latency and ITI responding thus showed similar patterns of change for this bird.

For B135, the rate of ITI responding was very low (0.45, 1.00, 0.60, and 0.18 responses per minute for FI lengths of 1, 2, 3, and 5 min, respectively), and ITI responding was unrelated to FI length. Intertrial interval responses were primarily "double-pecks", the first of which occurred during a trial.

*Variations in number of trials (FI length = 2 min).* For both B135 and B161, median response latency decreased across the interval (Figure 5, middle panels). The declines were comparable for all values of N except N = 15 for B135, and for all except N = 8 for B161. For these exceptions there was a somewhat increased latency toward the end of the interval. For both subjects, the latency of responding on a given trial was thus primarily dependent on the temporal location of that trial with regard to reinforcement.

Intertrial interval responding under these schedules was again minimal for B135. For B161, however, ITI responding under these schedules ranged from five to 13 responses per minute. These variations in ITI responding for B161 were not, however, systematically related to the values of N employed.

*Conjoint variations of FI length and N (cycle length = 15).* Median latency again decreased across the interval for B135 under all conditions (Figure 5, bottom left panel). The functions were quite comparable, except that median latencies were somewhat lower across the interval for the FI 1-min (4) and FI 2-min (8) schedules of reinforcement. For B161, however, no systematic latency decreases were seen under the FI 2-min (8) and FI 3-min (12) schedules (Figure 5, bottom right panel). While B135's ITI responding was again minimal under all conditions, rates of ITI responding for B161 were 2.4, 12.6, 6.4, and 0.8 responses per minute for the FI 30-sec (2), FI 1-min (4), FI

2-min (8), and FI 3-min (12) schedules, respectively. Except for the FI 30-sec (2) condition, rate of ITI responding again varied with FI length for B161.

### *Response Frequency*

*Variations in FI length (N = 15).* For both B135 and B161, the frequency of trial responding showed a negatively accelerated increase across the intervals (Figure 6, top panels). For B161, this increase was comparable under all FI lengths. B135, however, produced higher response frequencies early in the interval under longer FI lengths except for the FI 3-min, which fell between FI 1-min and FI 2-min. Also, trial responding reached maximum levels for both subjects when six to seven trials remained before reinforcement.

*Variations in N (FI length = 2 min).* For both B135 and B161, response frequencies again showed negatively accelerated increases across intervals (Figure 6, middle panels). Response frequency differences were again restricted to the early part of the intervals, where response frequency tended to be inversely related to N. Replotting these curves as a function of the number of trials remaining in the interval (not shown), trial responding again reached maximum levels seven trials before reinforcement for B135, and six trials before reinforcement for B161.

*Conjoint variations of FI length and N (cycle length = 15 sec).* Both birds again showed increases (usually negatively accelerated) in response frequencies under all conditions (Figure 6, bottom panels). The response frequency curves were not, however, simply related to the conjoint variations in FI length and N. An intermediate-valued schedule, FI 2-min (8), produced the highest response frequencies, especially during the first trial in the intervals. Conjoint variations in FI length and N both above and below this schedule produced decrements in response frequency early in the intervals.

### *Manipulation of Trial Duration*

The data for B419 and B522 are presented in Figure 7, with median latency data shown in the top two panels, and response frequency data shown in the bottom two panels. For B419, median latencies were quite long (>0.60 sec) at all three durations (Figure 7, upper left panel). The variability in latency was also large, with

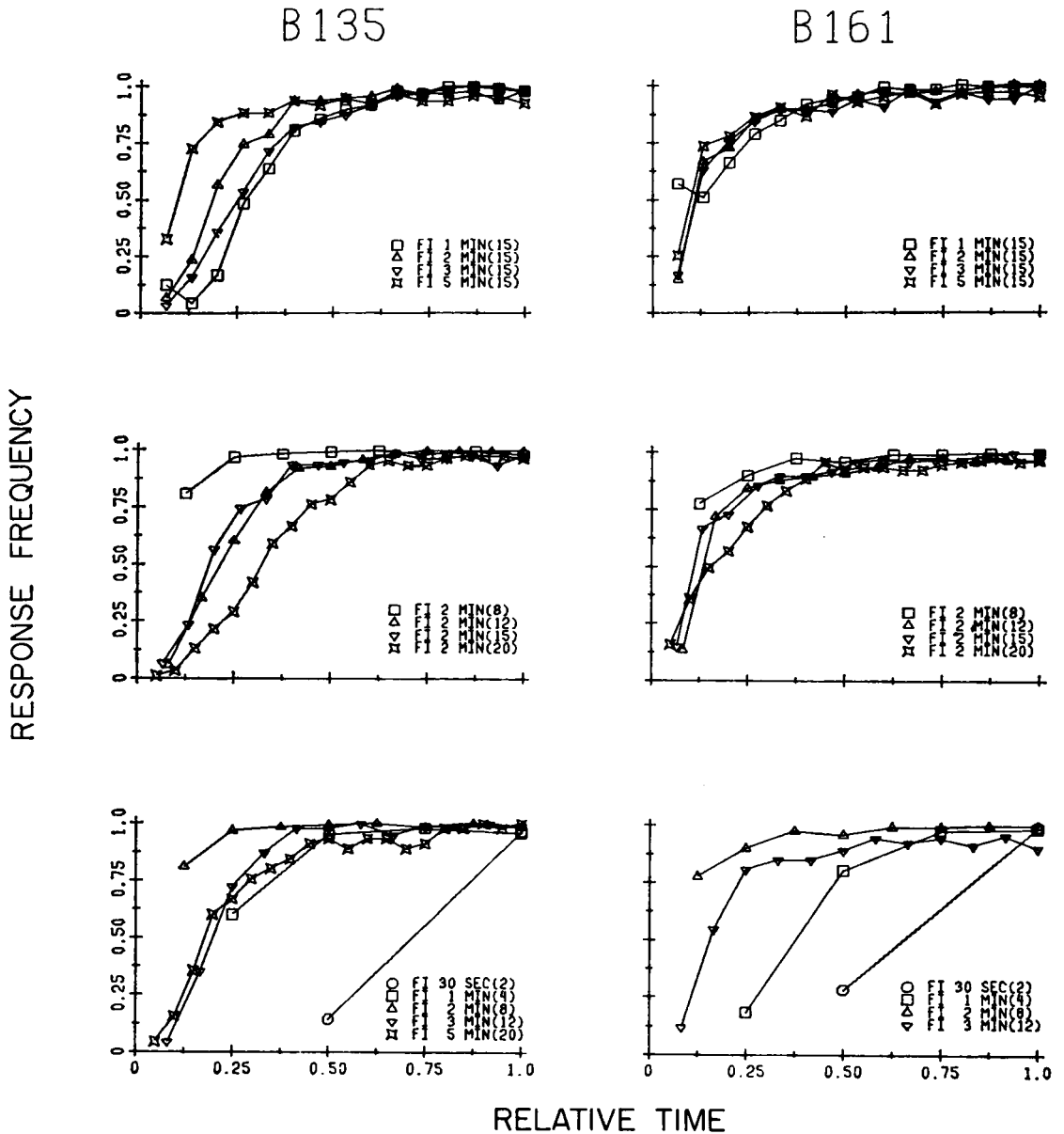


Fig. 6. Response frequency curves for B135 and B161 under all experimental conditions.

Q values generally being between 0.20 and 0.35 sec. Differences in latency occurred only during the first four trials, where latencies were longest for the 5.0-sec duration and shortest for the 1.75-sec duration. These differences are, however, small when compared to the variability in latency. Response frequencies for B419 were highest under the 10.0-sec duration; the 1.75- and 5.0-sec durations produced similar response frequencies except during the first three trials, where the shorter duration pro-

duced higher response frequencies (Figure 7, lower left panel).

For B522, median latency was remarkably stable following the sixth trial (Figure 7, upper right panel). Variability in latency was relatively low following the sixth trial. During the first four trials, the longer trial durations produced longer latencies and greater variability in latency. The latency differences were, however, generally smaller than the variability in latencies. Response frequency differences

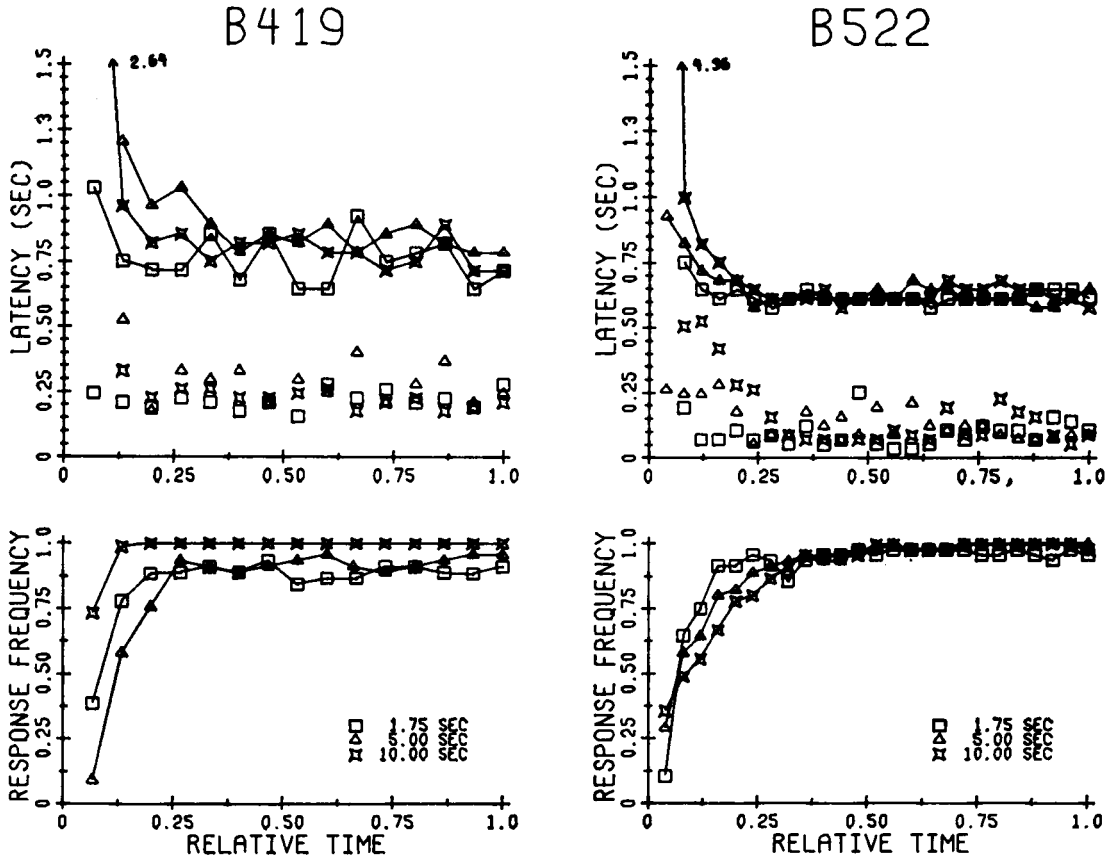


Fig. 7. Median response latency, Q values, and response frequency curves for B419 and B522 under three different trial durations (1.75, 5.0, and 10.0 sec). Schedules of reinforcement were FI 3-min (15) for B419, and FI 5-min (25) for B522.

were also restricted to the first six trials, with shorter durations producing higher response frequencies (Figure 7, lower right panel).

### DISCUSSION

The performances generated under the present discrete-trial FI schedules of reinforcement closely parallel the type of performance typically seen under free-operant FI schedules of reinforcement in a number of ways. (1) Acquisition of FI performance after prior training on CRF produces initial extinction-like patterns of responding. In the free-operant case, rate of responding falls off late in the interval after each reinforcement (Ferster and Skinner, 1957, pp. 136-142); in the present discrete-trial case, response latencies either increased or ceased to occur later in the interreinforcement interval, and trial responding was more infrequent later in the interval. (2) Stable perform-

ance under both conditions is characterized by little or no responding immediately after reinforcement. (3) During stable performance, pauses after reinforcement may be followed by either gradual or rapid transitions to a higher rate behavior. Thus, we have the gradual scalloping pattern (*e.g.*, Ferster and Skinner, 1957) and the break-run pattern (*e.g.*, Cumming and Schoenfeld, 1958) of free-operant FI performance, and correspondingly the inverted scallop and break-run cumulative latency patterns, and the individual break-run patterns of trial responding of the present discrete-trial FI performances. (4) In both situations, the relative "strength" of responding can vary as a function of the passage of relative time during the interval (elapsed proportion of total interval length). Relative rates of responding (local rates divided by terminal rate) for free-operant FIs are independent of variations in FI length when examined across relative time (Dews,

1970). Similarly, changes in median latency in the present study were independent of variations in FI length when examined across relative time (a discussion of the response latency changes of B161 follows). These similarities in performance under the free-operant and discrete-trial FI schedules of reinforcement suggest that the critical relations between behavior and reinforcement that are necessary for FI behavior are maintained in both situations.

A close parallel exists between the present procedure and that of Dews (1962), who presented alternating 50-sec periods of houselight-off ( $S^A$ ) and houselight-on ( $S^D$ ) during an FI 500-sec. The  $S^A$  periods disrupted the normal FI performance, but responding continued to increase over successive  $S^D$  periods. The FI character of the behavior was thus evident, even though responding was suppressed during alternating periods of the FI. Similarly, FI-like behavior was still observed under the present procedure, even though ITI responding was nearly eliminated and trial responding was limited to one response per trial. These observations, plus the above-mentioned similarities between discrete-trial and free-operant FI performances, suggest that the superimposition of discrete trials on an FI schedule does not appreciably affect the controlling relations between the schedule and behavior. Such a partitioning of the FI may, however, affect FI behavior when the partitioning elements can be differentiated, as in an FI with a discontinuous clock. The different stimulus elements of a clock become differentially associated with corresponding parts of the FI, and thus control different rates of responding (Segal, 1962). In the present procedure, however, the same stimulus change, brief keylight illumination, occurred at regular intervals throughout the FI. Thus, no single stimulus change could become differentially associated with a given part of the FI.

The response latency patterns of B135 were consistently related to the passage of relative time during the interval. Variations in the FI-length, N (minimum number of trials per interval), and trial-duration parameters had little or no effect on these latency patterns. The frequency of trial responding was, however, affected by these parameters. Response frequency during early trials in an interval tended to be directly related to FI length and inversely related to N. These observations sug-

gest the operation of a gradient of conditioned reinforcement for response frequency (each trial in a repetitive trial sequence ended with the conditioned reinforcer of trial termination). The effectiveness of this gradient would presumably depend on the number of trials in each interval (N) and/or their individual proximity to reinforcement. Increasing N would thus produce more trials closer in time to reinforcement and also more unreinforced trials per reinforcement. When N was increased independent of FI length, response frequency fell during the first part of the interval, indicating that number of trials per reinforcement was the important factor. Further, when FI length was increased independent of N, response frequency generally increased during the first part of the interval for B135, a result in direct opposition to the operation of a purely temporal gradient of conditioned reinforcement. This increased responding may be due to the interaction of two gradients—(1) a conditioned reinforcement gradient based on the number of trials per reinforcement, which would tend to maintain relatively constant response frequencies independent of FI length, and (2) an extinction-like gradient due to the  $S^A$ -like properties of reinforcement (Ferster and Skinner, 1957, p. 134), which would tend to reduce responding immediately after reinforcement. Assuming a constant  $S^A$ -like effect of reinforcement, greater response reductions would then occur under shorter FI lengths for those trials closely following reinforcement. Increasing the FI length would temporally move these trials away from the last reinforcement and thus produce higher response frequencies early in the interval.

In the series of jointly varied FI-length and N schedules, intermediate values of these parameters produced the maximum response frequencies early in the interval. Since cycle length was held constant under these schedules, the first trial in each interval occurred at the same time following reinforcement in each schedule. Any constant  $S^A$ -like effects of reinforcement would then be the same under all schedules for these early trials, and one might have thus expected response frequencies during these early trials to be solely an inverse function of N. This was, however, true only for N values of eight or greater. Another possibility is that extremely low values of N resulted in increased discriminability between

successive trials in terms of the occurrence of reinforcement on a given trial. One would then expect low response frequencies during these early trials. At higher N values, such a discrimination would presumably become more difficult, and the conditioned reinforcement properties of the trial sequence might then come to control the frequency of trial responding over successive trials.

The effects of variations in trial duration on response frequency were inconsistent. Differences in trial responding were restricted to the early part of the interval and for one subject, B522, response frequencies at this time were slightly higher under shorter trial durations. For the other subject, however, the highest response frequencies occurred under the longest trial duration. These inconsistent effects of trial duration on response frequency may be due in part to an order effect introduced by exposure to the shorter trial durations first. Since these subjects were not extensively exposed to the longer duration conditions, the response levels obtained under a given duration may also reflect an interaction between the previous baseline level of responding and the new trial duration.

The gradual changes in response latency observed in many individual intervals in the present study confirms the statement of Schneider and Neuringer (1972) that a two-state model of FI performance does not adequately characterize response latency changes under discrete-trial FI schedules. However, the present results also bring into question the generality of these authors' findings concerning response frequency. In the Schneider and Neuringer study, a constant cycle length was employed. Their procedures were thus comparable to the series of jointly varied FI-length and N schedules of the present study in which complex changes in response frequency occurred as a function of the schedule values. These data, plus the relationships observed between response frequency and the discrete-trial parameters of FI length and N, suggest that the generality of their findings may well be limited to such conjoint variations of FI length and N.

Finally, a comment regarding B161 is called for. As noted previously, this bird maintained substantial amounts of ITI responding under many of the schedules employed. Response frequency functions for B161 were remarkably

similar to those of B135, given this discrepancy in intertrial behavior. Response latency patterns were different, however, for B135 and B161 whenever FI length was manipulated (top and bottom panels of Figure 5). This difference may be characterized as an absence of the pattern of decreasing latencies for FI lengths greater than 2 min. Similarly, rates of ITI responding were low for FI lengths greater than 2 min (two responses per minute or less), and increased with shorter FI lengths. Finally, the latency distributions of B161 (Figure 4) showed greater variability and an increased frequency of unusually short latencies at short FI lengths, compared to those of B135. It is tempting to relate these observations as follows. At short FI lengths, the key-peck behavior of B161 was not controlled by the trial stimulus. Rather, responding proceeded nearly as it would have had the key been constantly illuminated. The "latency" functions of B161 were thus simply arbitrarily divided interresponse times. At short FI lengths [(e.g., FI 1-min (15)], ITI responding increased during the interval, and the corresponding "latency" curves declined across the interval. At longer FI lengths (greater than 2 min), ITI responding fell to low levels while trial responding was well maintained, indicating an increased control by the trial stimulus. The influence of frequent ITI responding on response latencies was thus reduced, and the latency curves of B161 rose. The increased control of responding by the trial stimulus was not great, however, since the latency curves of B161 were relatively flat, and median latencies were still extremely long (>0.90 sec).

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