EFFECTS OF CONCURRENT RESPONSE-INDEPENDENT REINFORCEMENT ON FIXED-INTERVAL SCHEDULE PERFORMANCE

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In three experiments, behavior maintained by fixed-interval schedules changed when response-independent reinforcement was delivered concurrently according to fixed- or variable-time schedules. In Experiment I, a pattern of positively accelerated responding during fixed interval was changed to a linear pattern when response-independent reinforcement occurred under a variable-time schedule. Overall response rates (total responses/total time) decreased as the frequency of response-independent reinforcement increased. Experiment II showed that the response-rate changes in the first experiment were controlled by the response-reinforcer relation, but the changes in patterns of responding were similar whether concurrently available reinforcement at varying times was response-dependent or response-independent. In the final experiment, the addition of response-independent reinforcement at fixed times to a fixed-interval schedule resulted in changes in both local and overall response rates and in the occurrence of positively accelerated responding between reinforcements. These results suggest that the temporal distribution of reinforcers determines response patterns and that both the response-reinforcement dependency and the schedule of reinforcement determine overall response rates during concurrently scheduled response-dependent and response-independent reinforcement.

Key words: fixed-interval schedules, fixed-time schedules, variable-interval schedules, variable-time schedules, concurrent schedules, response-independent reinforcement, key pecking, pigeons

The usual procedure for studying response-independent reinforcement has been to eliminate the response-reinforcement dependency by which behavior is being maintained. Generally, the primary effect of this procedure is to reduce the rate of response (Skinner, 1938; Zeiler, 1968). Elimination of the response-reinforcement dependency for a portion of the reinforcements results in response rates that decrease as the proportion of response-independent reinforcement increases. This latter effect has been demonstrated by maintaining the total number of reinforcers constant and varying the number that are response-dependent (Lattal, 1974) and by delivering additional response-independent reinforcement

while responding was maintained under a concurrently available schedule of response-dependent reinforcement (Edwards, Peek, and Wolfe, 1970; Green and Rachlin, 1975; Rachlin and Baum, 1972).

A second effect sometimes obtained following the transition to response-independent reinforcement is a change in the temporal distribution or pattern of responding. This effect depends in part on the temporal distribution of reinforcers under both the response-dependent and response-independent reinforcement schedules. Zeiler (1968) found that the transition from variable-interval (VI) to variable-time (VT) resulted in little change in temporal patterns of responding, but transitions from VI to fixed-time (FT) or fixed-interval (FI) to VT respectively resulted in increases and decreases in the degree of positive acceleration of response rates between successive reinforcements. Green and Rachlin (1975), Lattal (1974), and Rachlin and Baum (1972) found no systematic changes in response patterns following a transition from VI to combinations of VI and VT schedules. Edwards *et al.* (1970) also reported no systematic differences in response

patterns between fixed-ratio (FR) and combinations of FR and FT schedules.

In each of the studies cited, the response-reinforcer dependency primarily controlled response rates and the scheduling of reinforcement in relation to time determined the pattern of responding. The present experiments examined changes in FI performance during concurrently scheduled response-independent reinforcement. Behavior maintained by FI schedules has been studied in relation to a number of other variables, such as the response-reinforcement dependency (Shull, 1970; Zeiler, 1968) and reinforcement frequency. Catania and Reynolds (1968) found that terminal response rates and the response patterns during FI components were directly related to reinforcement frequency, but overall response rates were not differentially affected by the three frequencies studied. They also found that the addition of a second FI schedule with a probability of occurrence of 0.05 or 0.50 to an FI 240-sec schedule altered response patterns. Nevin (1971) found that overall response rates during FI generally decreased as the frequency of reinforcement increased during a concurrently available VI schedule on a second key. Response patterns during FI 200-sec, but not during FI 50-sec, became more linear as the frequency of VI reinforcement increased.

EXPERIMENT I

This experiment examined the effects of the concurrent delivery of response-independent reinforcement according to a VT schedule on key-peck responding maintained under an FI schedule.

METHOD

Subjects

Two mixed-breed pigeons with prior experience with an autoshaping procedure (Brown and Jenkins, 1968) were maintained at approximately 80% of free-feeding weights.

Apparatus

An operant conditioning chamber with a work area of 30 by 32 by 39.5 cm was used. A response key, operated by a force of 0.14 N, was located on the midline of the work panel 22 cm from the floor. The key was transilluminated by a yellow light at all times except during re-inforcement. Under all schedules, reinforcement was 3-sec access to mixed grain in a food hopper located behind a 5-cm square aperture 8.5 cm from the floor and on the midline of the work panel. The aperture was illuminated by a 7-W white light during reinforcement. A 7-W white houselight, located behind a piece of translucent plastic in the lower-right corner of the panel, provided general illumination in the chamber at all times except during reinforcement. White noise and a ventilating fan masked extraneous sounds. Electromechanical programming and recording equipment was located in an adjacent room.

Procedure

Since the birds had been trained to key peck previously, each was placed on an FI schedule and the interreinforcement interval was increased over several sessions to FI 5-min. Visual inspection of the overall response rates (total responses in session/total time in session) indicated that FI 5-min performance was stable after 31 and 40 sessions for Birds 1 and 2, respectively. Upon observing stable performance, a VT schedule was added, converting the schedule to concurrent FI 5-min VT (*cf.* Rachlin and Baum, 1972). During the concurrent schedule, the first key peck after 5 min produced reinforcement (FI 5-min) and reinforcement was concurrently available independently of the birds' behavior at varying time periods (VT x-min). An arithmetic progression was used to generate the VT schedule (*cf.* Catania and Reynolds, 1968). The two schedules operated independently and the timers arranging reinforcement under either schedule continued to operate during reinforcement under the other schedule. The effects of different frequencies of VT reinforcement were studied in the sequence shown in Table 1. The number of sessions that each schedule was in effect is also given for each subject. Ninety-minute sessions occurred during the first three conditions and 25-min sessions during the last two conditions. The shorter sessions were used during concurrent FI 5-min VT 0.5-min to prevent excessive weight gain during the session and during the last concurrent FI 5-min VT 1.5-min to ensure that shortening the session did not in itself affect response rates. Sessions were conducted six days a week.

Table 1

Number of sessions and mean and range of overall response rates during the last five sessions of each schedule in Experiment I.

	Bird 1			Bird 2		
Schedule	Number of Sessions	Responses per Minute	Range	Number of Sessions	Responses per Minute	Range
FI 5-min	34	60.2	55.8-66.3	45	87.2	80.4-94.2
conc FI 5-min VT 2.5-min	21	74.6	63.4-81.4	20	89.3	85.3-92.4
conc FI 5-min VT 1.5-min	20	62.3	55.1-67.6	15	85.3	77.4-88.6
conc FI 5-min VT 0.5-min	31	56.4	50.2-58.2	30	71.9	59.6-76.7
conc FI 5-min VT 1.5-min	9	61.2	43.6-77.8	7	81.7	74.2-88.4

RESULTS

Table 1 shows that the overall response rates for Bird 1 increased from the FI 5-min schedule when concurrent FI 5-min VT 2.5-min was in effect. Further increases in the frequency of VI reinforcement led to successive reductions in overall response rates for both birds.

Figures 1 and 2 show that the FI 5-min schedule and the concurrent schedules controlled markedly different local response rates and patterns of responding. Beginning with the first session of the concurrent schedule, response patterns between successive FI reinforcements changed from positively accelerated to linear. Subsequent changes in the frequency of VT reinforcement reduced the local response rates but did not change the patterns of responding. Mean quarter-life values (*cf.* Gollub, 1964) for Birds 1 and 2 during FI 5-min were 0.42 and 0.45. The quarter-life

values during the concurrent FI 5-min VT schedules ranged between 0.24 and 0.28 for each bird.

EXPERIMENT II

Experiment I showed that concurrently available response-independent reinforcement at variable-time periods considerably altered the patterns of responding maintained by FI reinforcement. The second experiment examined the role of the response-reinforcement dependency in such changes in performance.

METHOD

Subjects

Four White Carneaux pigeons with prior experience with various schedules of reinforcement were maintained at approximately 80% of free-feeding weights.

Apparatus

The apparatus was the same as in the first experiment except that the response key was transilluminated by either a green or white stimulus light and the reinforcement duration was 4-sec.

Procedure

Since all birds had key-pecking experience, each was placed on multiple (*mult*) FI 5-min FI 5-min in which the two components were presented in random order and were associated with green or white transillumination of the response key. Components changed only after the delivery of FI reinforcement. When stable responding, as determined by visual inspection of the overall response rates, was obtained in both components, the schedules were changed
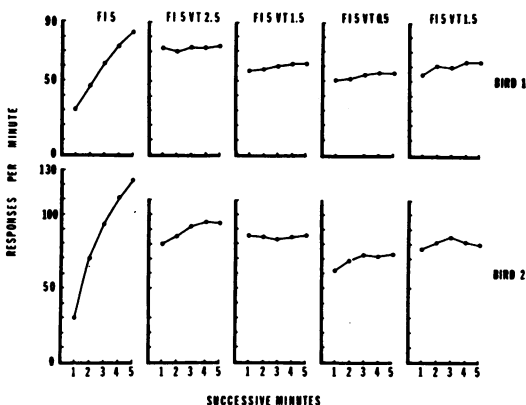

Fig. 1. Responses per minute (total responses/total time in session) during successive minutes of the FI for Birds 1 and 2. Each data point is the mean of the last five days at the condition indicated above the graphs.

FI5

CONC FI5 VT 2.5
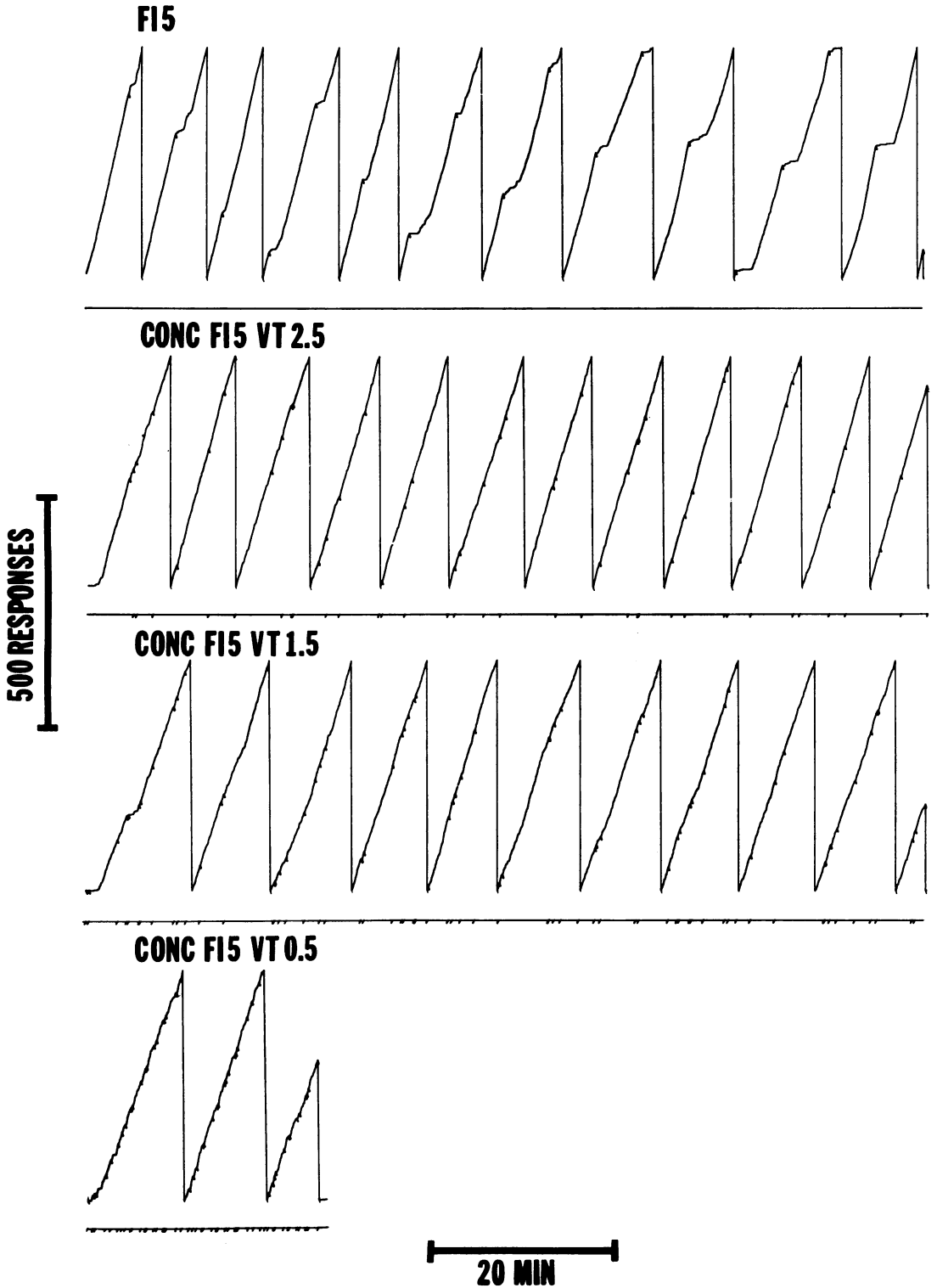
500 RESPONSES

CONC FI5 VT 1.5

CONC FI5 VT 0.5

20 MIN

Fig. 2. Illustrative cumulative records of the performance of Bird 2 during the conditions indicated above each record. Each record depicts a complete session. Deflections of the response pen indicate reinforcement and deflections of the event pen below each record indicate response-independent reinforcements.

Table 2

Number of sessions and sequence of schedules for each bird in Experiment II. The quarter-life values are the mean (top) and range (bottom) of the last five sessions at each condition.

	Bird 3			Bird 4		
	Number of Sessions	Quarter Life		Number of Sessions	Quarter Life	
Schedule		Green	White		Green	White
mult FI 5-min FI 5-min	10	0.37	0.39	12	0.47	0.44
		(0.33-0.43)	(0.34-0.45)		(0.37-0.52)	(0.37-0.52)
mult (*conc* FI 5-min VT 1.5-min)	36	0.25	0.25	27	0.29	0.27
(*conj* FI 5-min VI 1.5-min)		(0.23-0.28)	(0.23-0.26)		(0.25-0.31)	(0.27-0.28)
mult (*conc* FI 5-min VT 0.5-min)	—	—	—	—	—	—
(*conj* FI 5-min VI 1.5-min)						
mult FI 5-min FI 5-min	12	0.39	0.39	13	0.33	0.34
		(0.36-0.44)	(0.36-0.43)		(0.34-0.42)	(0.28-0.37)

	Bird 5			Bird 6		
	Number of Sessions	Quarter Life		Number of Sessions	Quarter Life	
Schedule		Green	White		Green	White
mult FI 5-min FI 5-min	22	0.51	0.49	10	0.45	0.42
		(0.43-0.55)	(0.45-0.51)		(0.41-0.51)	(0.36-0.46)
mult (*conc* FI 5-min VT 1.5-min)	25	0.40	0.30	32	0.34	0.28
(*conj* FI 5-min VI 0.5-min)		(0.33-0.43)	(0.28-0.32)		(0.33-0.35)	(0.27-0.30)
mult (*conc* FI 5-min VT 0.5-min)	—	—	—	15	0.33	0.26
(*conj* FI 5-min VI 0.5-min)					(0.30-0.36)	(0.23-0.27)
mult FI 5-min FI 5-min	12	0.44	0.39	20	0.40	0.37
		(0.38-0.52)	(0.30-0.44)		(0.31-0.48)	(0.30-0.47)

as indicated in Table 2. During the white light, key-peck responses were reinforced according to both a FI 5-min schedule and a VI 1.5-min schedule. During the green light, key-peck responses were reinforced according to a FI 5-min schedule and response-independent reinforcement occurred according to a VT 1.5-min schedule. Reinforcement under the VT and VI schedules was independent of FI reinforcement and was scheduled according to the constant probability equation provided by Catania and Reynolds (1968, Appendix II). According to the nomenclature suggested by Rachlin and Baum (1972) and Catania, Deegan, and Cook (1966), the two components of the multiple schedule were concurrent FI 5-min VT 1.5-min and conjoint (*conj*) FI 5-min VI 1.5-min. This schedule was in effect until overall response rates appeared stable upon visual inspection. The value of the VI and VT schedules was then changed to 0.5 min for Bird 6 for 15 sessions. All birds were subsequently returned to *mult* FI 5-min FI 5-min. Sessions were conducted five days a week and each lasted for 100 min, except that the session duration was decreased to 50 min for Bird 6 to eliminate excessive weight gain when VI 0.5 min and VT 0.5 min were scheduled with FI 5-min in the two components.

RESULTS

Figure 3 shows responses per minute in both components during the last five sessions of each schedule. The relevant comparisons are between components within a given condition and within components across the different conditions. Response rates in the two components under *mult* FI 5-min FI 5-min did not differ systematically. *Conj* FI 5-min VI (associated with the white light) generally maintained higher rates than did *conc* FI 5-min VT (associated with the green light). Bird 6 did not show this effect during two of the sessions shown. Comparing across conditions, with all birds but Bird 4, *conc* FI 5-min VT 1.5-min controlled lower mean response rates than did the previous FI 5-min schedule in that component. Response rates for Bird 4 increased in the green component from FI 5-min to *conc* FI 5-min VT 1.5-min. Response rate during
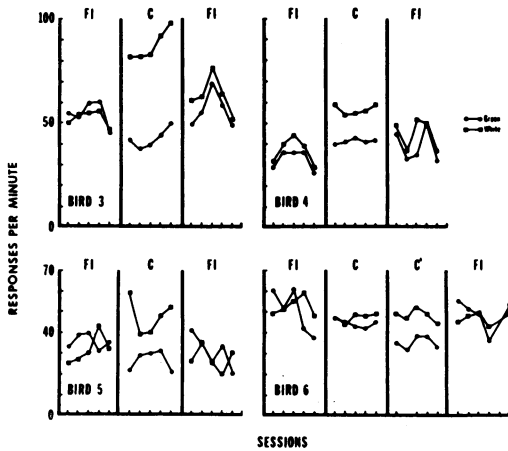
Fig. 3. Responses per minute of Birds 3, 4, 5, and 6 during the last five sessions of each condition in both components (associated with green and white stimulus lights) of the multiple schedule. Above each graph, FI refers to *mult* FI 5-min FI 5-min; C refers to *mult* (*conc* FI 5-min VT 1.5-min) (*conj* FI 5-min VI 1.5-min); and C' (Bird 6) refers to *mult* (*conc* FI 5-min VT 0.5-min) (*conj* FI 5-min VI 0.5-min).

conj FI 5-min VI 1.5-min was higher than during the FI 5-min schedule with all birds except Bird 6. Changing the frequency of VI and VT reinforcement with this bird caused response rates to decrease further in the conjoint schedule but did not change rates in the concurrent schedule.

Local rate changes similar to those described in the first experiment occurred in both components. Quarter-life values for all conditions are shown in Table 2. In both components, the quarter-life values show that responding became more uniformly distributed throughout the FI during the concurrent and conjoint schedules. Systematic differences between the quarter-life values in the two components did not occur. *Mult* FI 5-min FI 5-min controlled characteristic patterns of positively accelerated responding in both components.

EXPERIMENT III

The first two experiments examined changes in rates and patterns of responding produced by the addition of reinforcement delivered at variable time periods. In the final experiment, changes in FI schedule performance were studied as a function of response-independent reinforcement after fixed time periods within a FI component.

METHOD

Subjects

Three mixed-breed pigeons with experience on VI schedules were maintained at approximately 80% of free-feeding weights.

Apparatus

The apparatus was the same as that used in the first experiment, except that the response key was transilluminated with a white light and reinforcement duration was 4-sec.

Procedure

Since each subject previously had learned to key peck, each was placed on an FI schedule

Table 3

Number of sessions and mean and range of overall response rates during the last seven sessions of each condition in Experiment III.

| | Bird 7 | | |
| | Number of Sessions | Responses per Minute | Range |
Schedule			
FI 3-min	41	59.4	56.7-63.4
FI 3-min + FT 1-min	33	26.9	25.4-28.8
FI 1-min	13	45.9	43.2-50.7
FI 1-min + FT 0.33-min	14	48.2	44.3-51.3
FI 0.33-min	8	48.9	42.7-53.8

| | Bird 8 | | |
| | Number of Sessions | Responses per Minute | Range |
Schedule			
FI 3-min	32	39.8	36.4-43.8
FI 3-min + FT 1-min	54	19.0	17.8-20.3
FI 1-min	30	37.2	33.0-40.7
FI 1-min + FT 0.33-min	10	12.8	10.9-14.9
FI 0.33-min	7	30.6	26.5-33.1

| | Bird 9 | | |
| | Number of Sessions | Responses per Minute | Range |
Schedule			
FI 3-min	—	—	—
FI 3-min + FT 1-min	—	—	—
FI 1-min	35	34.7	31.4-37.2
FI 1-min + FT 0.33-min	35	46.1	41.2-51.7
FI 0.33-min	21	40.6	34.9-43.1

and the value of the FI was increased over several sessions. The sequence and number of sessions at each schedule are shown in Table 3. Two of the birds were trained on FI 3-min but Bird 9 showed poor schedule control under the FI 3-min, *i.e.*, inappropriate pauses in responding and low response rates. The value of the FI was decreased to 1 min for this subject. When stable FI performance was observed, response-independent reinforcement was delivered at fixed times within each FI. For Birds 7 and 8, response-independent reinforcement occurred after the first and second minute of each FI 3-min segment. For Bird 9, response-independent reinforcement was delivered after the first and second 0.33-min period of each FI 1-min component. The same clock and stepping relay were used to program both FI and FT reinforcement. As a result, a response-independent reinforcement occurred when the stepping relay reached the third and fifth position and the response-dependent reinforcer was made available when the seventh position of the stepping relay was reached. A failure to complete, or a delay in the completion of, the FI requirement could therefore affect the subsequent occurrence of response-independent reinforcement, although this did not happen during the experiment. When key pecking was stable under this schedule, the schedule was changed to FI 1-min for Birds 7 and 8 and to FI 0.33-min for Bird 9 to assess the effects of adding the response-reinforcement dependency. Bird 9 broke its beak before reaching stable performance on FI 0.33-min and it was removed from the experiment at that point. When the key pecking of Birds 7 and 8 was stable on FI 1-min, response-independent reinforcement was delivered to these birds after the first and second 0.33-min period of each FI 1-min component. FI 0.33-min was the final schedule. Session duration varied for individual subjects due to differences in numbers of reinforcements under the different conditions. Each schedule was in effect until the overall key-pecking response rates were stable according to the criterion of Schoenfeld, Cumming, and Hearst (1956).

RESULTS

Table 3 shows the mean and range of overall response rates during the last seven days of each condition. Increases in the frequency of reinforcement by the addition of response-independent reinforcement during FI 3-min decreased overall response rate for Birds 7 and 8. The subsequent change to FI 1-min increased overall response rates of Birds 7 and 8. The addition of FT 0.33-min to FI 1-min had mixed effects on overall response rates, as did the subsequent change to FI 0.33-min.
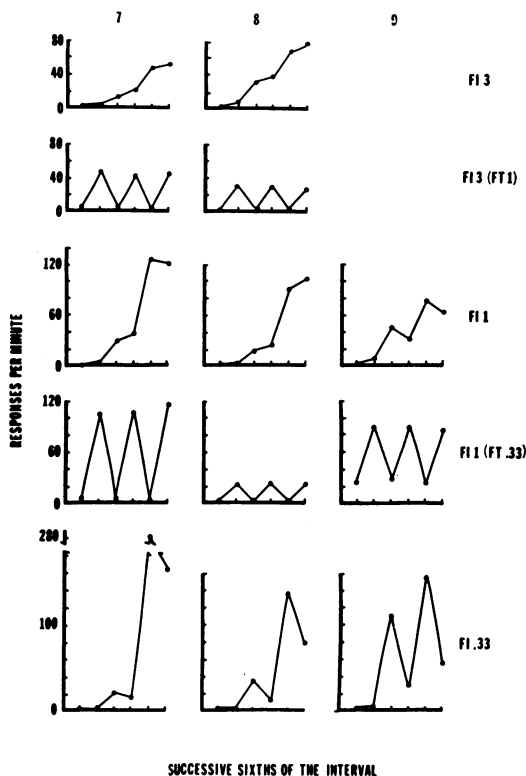

Fig. 4. Responses per minute during successive sixths of the FI for Birds 7, 8, and 9. Each data point is the mean of the last five days at the condition indicated to the right of the graphs. During the conditions with added FT reinforcement, such reinforcement occurred at the end of the second and fourth sixth of the interval.

Figures 4 and 5 show that positively accelerated responding occurred during each FI (quarter-life values ranged from 0.41 to 0.60 for all birds). There was some variability in this pattern during FI 0.33-min. Introduction of reinforcement after the second and fourth sixths of the interval disrupted these baseline patterns and resulted in positively accelerated responding between each successive reinforcement regardless of whether such reinforcement was response-dependent or response-independent.

FI 3

FI 3(FT 1)

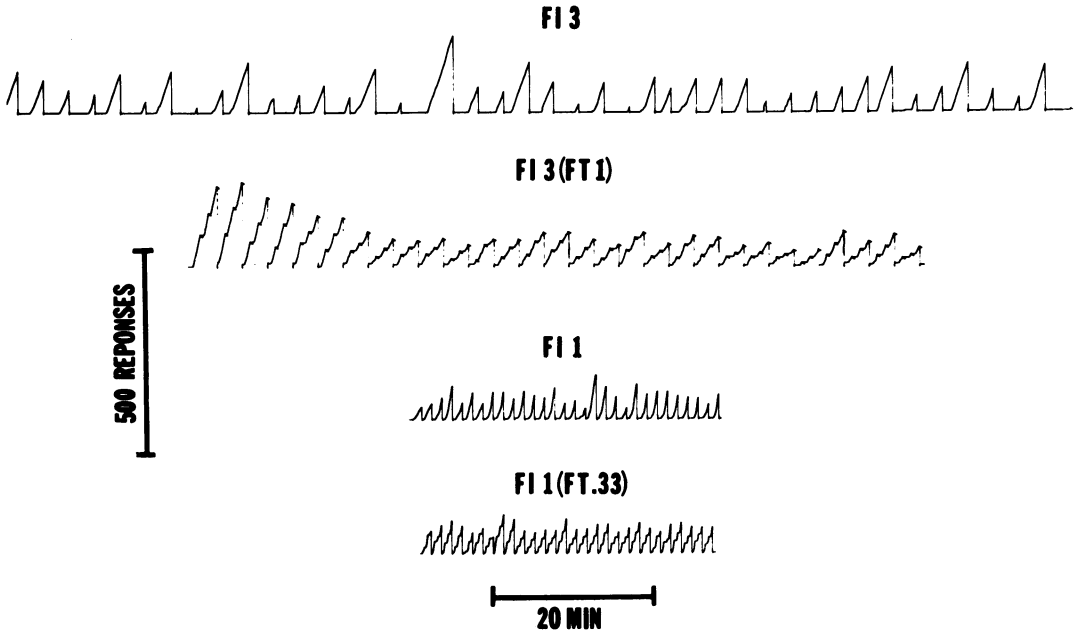500 REPONSES

FI 1

FI 1(FT.33)

20 MIN

Fig. 5. Illustrative cumulative records of the performance of Bird 7 during the conditions indicated above each record. See text for a complete description of the conditions. Each record depicts a complete session. The response pen reset following a response-dependent reinforcer during all conditions. Response-independent reinforcement is indicated by a deflection of the response pen during the FI 3 (FT 1) condition. Such reinforcement is not indicated during the FI 1 (FT 0.33) condition, but the location of each response-independent reinforcement was at the beginning of each pause in responding shown on the record.

GENERAL DISCUSSION

Zeiler (1968) studied schedules in which the response-reinforcement dependency was either always or never in effect. He concluded that the overall response rate was controlled primarily by the response-reinforcement relationship and that the patterns of responding were primarily controlled by the temporal distribution of reinforcements. Subsequent experiments, including the present ones, have supported aspects of this general conclusion but also offer certain constraints on the generalization (e.g., Alleman and Zeiler, 1974). Variables relevant to the control of responding during concurrently available response-dependent and response-independent reinforcement in the present experiments were the response-reinforcement dependency, the schedules of response-dependent and response-independent reinforcement, and the frequency of response-independent reinforcement. Each of these variables will be considered separately.

In several previously cited studies, the rate of responding decreased when response-independent reinforcement either replaced or oc-

curred concurrently with a schedule of response-dependent reinforcement. This was generally true in the present study as well. In Experiment II, conj FI 5-min VI maintained higher response rates than did conc FI 5-min VT. In Experiment III, Birds 7 and 8 exhibited higher rates during FI 3-min and FI 1-min than during the combined FI 3-min and FT 1-min condition. In several instances, however, the addition of response-independent reinforcement either did not systematically change overall response rates or even increased them. For example, overall response rates increased following a change from FI 5-min to conc FI 5-min VT 2.5-min with Bird 1; from FI 5-min to conc FI 5-min VT 1.5-min with Bird 4; and from FI 1-min to the addition of FT 0.33-min within each FI 1-min with Birds 7 and 9.

One problem related to the control of response rates is that of temporal contiguity of the key-peck response and response-independent reinforcement. Response rates were relatively high in this and other related studies (Lattal, 1974; Rachlin and Baum, 1972) and the adventitious reinforcement of key pecking

must be considered as one source of control of the response rates of some of the birds. Indeed, in these experiments it is somewhat surprising that adventitious reinforcement did not occur more consistently to produce higher response rates during the concurrent schedules. Such a variable is not easily controlled, since there cannot be an explicit contingency such as a changeover delay (COD) between responding on the key and the delivery of response-independent reinforcement. If a COD were used, the nature of the concurrent schedule would change, since the previously response-independent reinforcement would become reinforcement for not pecking the key.

The marked changes in local response rates or response patterns also contribute to the increases in overall rates observed in Birds 1, 4, 7, and 9 under the conditions described above. Since the overall rate is an average of local rates of responding, and the local rates shift so markedly during the schedules studied, variability in overall rates is to be expected. Experiments II and III further showed that the pattern of responding was controlled by the temporal distribution of reinforcements and not by the response-reinforcement dependency. In comparing these results to those found when VT and VI are concurrently available, it appears that local response rates are affected more by schedules of response-independent reinforcement concurrently available with FI than with VI. One constraint on this observation is that data from *conc* VI FT schedules have not been reported.

The frequency of response-independent reinforcement when such reinforcement occurs either in isolation or in conjunction with VI reinforcement controls response rates (Lachter, 1971; Lachter, Cole, and Schoenfeld, 1971; Rachlin and Baum, 1972). The control of FI responding by the frequency of response-independent reinforcement is shown most clearly in Experiment I but also in the data from Bird 6 in Experiment II. In both of these examples, response rates decreased when the frequency of response-independent reinforcement increased. Different frequencies of VT reinforcement in Experiment I did not differentially affect the patterns of responding during FI (*cf.* Nevin, 1971).

Matching of the proportion of responses between two concurrently available operanda and the proportion of reinforcements during concurrently available VI schedules is commonly found (*e.g.,* Catania, 1962; Rachlin and Baum, 1972). Rachlin and Baum (1972) reported an extension of this relationship to concurrent VI VT schedules by the use of relatively large values for the constants in one of Herrnstein's (1970) equations. Their mathematical analysis was based on median data from a number of different concurrent schedules of which the response-reinforcement relationship was one parameter. One difficulty in applying such an analysis to concurrent schedules involving response-independent reinforcement is the broadness of the class of responses that potentially can be changed by such reinforcement. A second difficulty concerns the assumption of independence of the two schedules (Herrnstein, 1970). Key pecking is consistently associated with response-dependent reinforcement, but response-independent reinforcement may occur in either the presence or absence of a key peck and, as previously suggested, the introduction of a COD changes the nature of the schedule. Nevin's (1971) data suggest a general sensitivity of response rates to the proportion of FI reinforcement during *conc* FI VI, and the data from Experiment I suggest a similar effect during *conc* FI VT despite the lack of programmed independence between the two conditions, although a precise matching relation did not appear to occur in either experiment.

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