VARYING RESPONSE-REINFORCER CONTIGUITY IN A RECYCLING CONJUNCTIVE SCHEDULE

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Three experiments describe the effects of manipulating the frequency of response-reinforcer contiguity in a recycling conjunctive schedule. The schedule arranged that a reinforcer was delivered after 30 s provided at least one response had occurred; otherwise the next cycle started immediately. In Experiment 1, this schedule produced the typical pause-respond-pause pattern, with most responses at mid-interval; and, when a limited number of contiguities between responses and food delivery were added, the pattern became more like the monotonic scallop seen on fixed-interval schedules. In Experiment 2, the schedule was initially presented with an additional contingency that allowed contiguity on every trial. Fixed-interval-like behavior occurred and tended to persist as contiguities were gradually eliminated. In Experiment 3, the recycling conjunctive schedule alternated with a condition in which a large number of contiguities occurred. The pause-respond-pause pattern and fixed-interval-like performance occurred with few or many contiguities, respectively. The results of all three experiments illustrate how contiguity interacts with a small number of other variables to determine performance on interval schedules and illuminate previous findings with fixed-interval and fixed-time schedules.

Key words: conjunctive schedule, fixed-interval schedule, fixed-time schedule, response dependency, contiguity, lever press, rats

Two general approaches to the analysis of schedule-controlled behavior have been taken. On the one hand, Morse and Kelleher (1977) suggested that schedules should be regarded as fundamental determinants of behavior, because it is only when a schedule specifies which variables operate in conjunction with one another that a distinctive performance emerges. In contrast, other investigators have noted similarity in the effects of certain variables across several schedules and have attempted to reduce the interpretation of schedule performance to a catalogue of the effects of, and interactions between, a number of variables. For example, Zeiler (1977) was able to show that one variable, the delivery of reinforcers at regular intervals, has characteristic effects that seem to be similar across a number of schedules. The simplest implementation of

this variable is fixed-time (FT) reinforcer delivery, which is identical to a Pavlovian (classical) temporal conditioning procedure. The complex temporal pattern of behavior that is produced by this schedule appears in the form of two classes of behavior that predominate in different parts of the interreinforcer interval. These are sometimes termed "interim" and "terminal" behavior patterns (Staddon, 1977).

Given that an FT procedure produces a particular behavioral pattern, it is possible to assess the extent to which this pattern contributes to performance on a schedule that arranges a similarly fixed interreinforcer interval, but which also sets up a contingency between the occurrence of a specific response and reinforcer delivery. Such an assessment was made by Anderson and Shettleworth (1977), who trained hamsters on FT and fixed-interval (FI) schedules of food reinforcement. They found that the activities that had been classified as interim or terminal on the FT schedule fell into the same categories on the FI schedule. Furthermore, terminal activities on the FI schedule were directed towards the lever, with the result that lever pressing was also recorded as a terminal activity. These findings led the authors to concur with Stad-

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don and Simmelhag's (1971) proposition that response contingencies simply select from among those activities that are facilitated by temporal proximity to food. However, substantial differences in performance between FT and FI schedules have been reported by some experimenters (e.g., Fenner, 1980), suggesting that the introduction of a contingency also potentiates the operation of other variables.

In order to identify these variables, it may be helpful to consider the ways in which a periodic response-independent reinforcer procedure (i.e., an FT schedule) can be changed into a response-dependent procedure. If the response requirement is a single response for a reinforcer (fixed ratio 1, or FR 1), then such a schedule is a combination of FT and FR 1 components. Three such schedules have been investigated: the FI (or tandem FT FR 1; after Zeiler, 1968), the conjunctive FT FR 1 (Powers, 1968; Shull, 1970), and the recycling conjunctive FT FR 1 (Staddon & Frank, 1975). In the FI schedule, a single response produces a reinforcer only when the FT component has expired. In contrast, the conjunctive schedule imposes no temporal restrictions regarding where within the interval the FR 1 component may be executed, although here also, a reinforcer is presented only when both component requirements have been satisfied. That is, if a response occurs within an FT component, then a reinforcer is delivered when the FT component terminates; if the FT component expires without a response having been made, then reinforcer delivery is produced immediately by the next response. In the recycling conjunctive schedule, a reinforcer is presented at the termination of the FT component if, and only if, a response has occurred within that component. On those occasions when an FT component terminates without a response having been made, reinforcer delivery is omitted and the next FT component begins.

The configurations of FT and FR 1 components represented by each of these schedules differ only in the extent to which restrictions are placed on the location of the response dependency. It is this aspect of the periodic structuring of the contingencies that may well play a crucial role in determining the types of response-reinforcer interactions possible in each schedule, and consequently the baseline performances maintained by each schedule.

Keenan (1982) and Keenan and Leslie (1984) manipulated the location of the response dependency in schedules with variable or fixed interreinforcer intervals. In the latter study, for example, rats were initially trained on a recycling conjunctive FT 30-s FR 1 schedule of reinforcement with food. The location of the response dependency was then restricted to a 10-s period within the FT component. By varying the location of this period within the FT component, the authors were able to demonstrate that the time from food delivery to the location of the response dependency (the F-RD interval) could control rate and pattern of responding. In the light of these findings, Keenan and Leslie argued that an FI schedule confounds the F-RD interval with the duration of the interreinforcer interval, thus raising the possibility that the F-RD interval is an important variable that has hitherto been overlooked in the study of FI schedules.

Another important variable involved in the structural diversity of the three schedules considered here (i.e., FI, conjunctive FT FR 1, and recycling conjunctive FT FR 1) is the opportunity for response-reinforcer contiguity to contribute to performance. Of the three schedules, only the FI schedule ensures contiguity between every reinforcer and a response. In the conjunctive schedule, contiguity is assured only if the response terminating the postreinforcement pause (PRP) occurs outside the FT component. Fortuitous contiguities are possible, however, as indeed they are in the recycling conjunctive where no contiguity is explicitly arranged. No experiments have directly compared performance on all of these schedules, but sufficient evidence exists to indicate that the different likelihoods of contiguity contribute significantly to the different rates and patterns of responding seen on the three schedules. Staddon and Frank (1975), for example, found response rates to be consistently higher on a conjunctive schedule than on its recycling counterpart over a range of interval durations, whereas Morgan (1970) and Shull (1970) found that response rates were higher on FI than on conjunctive schedules. Similarly, a pause-respond-pause pattern tends to develop on conjunctive schedules (Shull, 1970) rather than an FI-like pattern, and this effect is more pronounced on recycling conjunctive than on simple conjunctive schedules (Staddon & Frank, 1975).

Table 1

Sequence of conditions, numbers of sessions, and percentage efficiency over the last five sessions in each condition of Experiment 1. Figures in parentheses are standard deviations of the session means for the percentage efficiency.

Rat no.	Conditions					
	1		2		3	
	No. of sessions	Efficiency (%)	No. of sessions	Efficiency (%)	No. of sessions	Efficiency (%)
F5	15	82 (2.0)	15	83 (6.7)	12	81 (4.2)
F6	32	85 (4.5)	15	88 (5.0)	13	94 (2.6)
F2	17	91 (6.0)	13	79 (5.3)	11	89 (7.4)
F3	19	91 (0.9)	13	90 (6.0)	12	91 (8.9)
F7	26	87 (2.8)	18	81 (6.0)	9	86 (2.6)
F8	25	94 (1.7)	16	93 (3.6)	13	99 (0.7)

The experiments described here augment the above findings by using procedures that directly manipulate the incidence of contiguity obtained on a recycling conjunctive schedule. This schedule was used to examine the effects of contiguity because (unlike an FI schedule) it does not confound the F-RD interval with the interreinforcer interval, and in the unmodified form of the schedule, contiguity between a response and a reinforcer is very unlikely. The first experiment simply examined whether varying the incidence of contiguity can affect patterning and response rates obtained on a recycling conjunctive schedule.

EXPERIMENT 1

METHOD

Subjects

Six male hooded rats, about 9 months old at the start of the experiment, were used. All had previous exposure to a recycling conjunctive FT 30-s FR 1 schedule of reinforcement; the experimental history of 2 of the animals, F5 and F6, is reported by Keenan and Leslie (1984). The animals were caged singly with water freely available; they were maintained at approximately 80% of their free-feeding body weights by feeding after experimental sessions. Artificial lighting was provided in the cage from 7:30 to 19:30 daily.

Apparatus

A standard Campden Instruments rat test chamber (Model CI 410) was situated in a sound-attenuating housing. The reinforced

response was pressing the lever, which was mounted 3 cm above and to the left of the food tray; the lever required a force of at least 0.1 N. Pressing the other lever, which was mounted 3 cm above and to the right of the food tray, had no scheduled consequences. The reinforcing event consisted of 5-s access to 0.1 mL of 5% (by weight) sucrose solution, delivered into a recessed tray at floor level. The tray was covered by a lightly hinged clear plastic flap and was illuminated by a 2.8-W bulb during reinforcer delivery. A 2.8-W houselight was mounted in the center of the ceiling and remained on throughout the session. A Nova® 2 computer (Data General Corp.) programmed contingencies and collected data.

Procedure

The sequence of conditions and the numbers of sessions in each condition are given in Table 1. Condition 1 was a recycling conjunctive FT 30-s FR 1 schedule of reinforcement. In this condition at least one response anywhere within a 30-s cycle produced sucrose at the end of that cycle. Any cycle in which no lever press occurred ended without sucrose and without delivery of any other stimuli; the next cycle began immediately. In all conditions, each session terminated after 100 reinforcers, and each animal received one session daily. Inasmuch as each rat received differing numbers of cycles per session, the number of cycles with reinforcement expressed as a percentage of the total number of cycles in the session was used as a measure of

Fig. 1. Mean number of responses in successive sixths of the 30-s cycle immediately after reinforcement, for each animal in each condition of Experiment 1.

performance efficiency. Behavior was considered stable when the mean efficiency over five consecutive sessions was greater than 70%, with a standard deviation less than 15% of this value (see Table 1). This stability criterion was used for all conditions.

In Condition 2, some programmed response-reinforcer contingencies were introduced. To limit the number of contingencies that would occur, the following procedure was used. The FT component was extended by 5 s, but the FR 1 requirement was operative only during the first 30 s of a cycle (i.e., a response emitted within that time produced a reinforcer at the end of the 35-s cycle). Failure to respond within the first 30 s of a cycle meant that the reinforcer was omitted at the end of that 35-s cycle. In addition, if the FR 1 requirement was met within the first 10 s of a cycle, a further response between 30 s and 35 s produced a reinforcer immediately and terminated the cycle. This procedural change was introduced to ensure a moderate number of response-reinforcer contingencies. To distinguish a response-reinforcer contingency produced in this way from occasions when the rat

made an additional response at the very end of the 35-s cycle but had not responded within the first 10 s of the cycle, the former will be termed programmed "zero-delay" reinforcement. If one or more responses occurred only between 30 s and 35 s had no effect. Condition 2, then, did not change the FR 1 requirement for reinforcement, but arranged that on occasions when that requirement was met early, zero-delay reinforcement might also occur.

Although the rat's behavior determined the maximum number of zero-delay reinforcements in Condition 2, this maximum was specified by the schedule in Condition 3. The mean percentage of zero-delay reinforcements obtained over the last five sessions in Condition 2 was calculated for each animal. Using a probability generator, these values were used to determine individually the probability with which the first response in the terminal 5 s produced zero-delay reinforcement. If the first response in this period did not produce reinforcement, then subsequent responses were ineffective. Apart from this change in proba-

Fig. 2. Upper panels: mean response rate during the last five sessions of each condition for each animal in Experiment 1. Bars indicate standard deviations of the session means. Lower panels: corresponding median postreinforcement pauses, in seconds.

bility, the procedure used here was the same as that used in Condition 2.

RESULTS

The results presented here for each animal are means calculated over the last five sessions in each condition. Figure 1 shows the rate of responding as a function of time since reinforcer delivery for each animal in each condition. During Condition 1, responding for all animals was characterized by relatively few responses immediately after reinforcer delivery, followed by an increase in the number of responses in the middle of the cycle and (for all but one animal) a gradual decrease in responding towards the end of the cycle. Response rates were relatively low for all animals, varying between 5 and 12 responses per minute (Figure 2, upper panels), and median postreinforcement pauses (PRPs) ranged from 8 to 14 s across animals (Figure 2, lower panels). Although the changes in response rate

across the interreinforcer interval were quite small in Condition 1, Figure 1 shows that for all animals (except F2) there was an increase in average response rate from the beginning to the middle of the interval and a decline from the middle to the end. Thus, a pause-respond-pause pattern characterized responding within the interreinforcer interval in Condition 1.

In Condition 2, both overall response rates and median PRPs increased in 5 of 6 animals (Figure 2, upper and lower panels, respectively). Similarly, 5 of 6 animals showed increases in responding in the last one third of the interval, while effects were inconsistent earlier in the interval (Figure 1). (Note that although the FT component was extended by 5 s, the occurrence of zero-delay reinforcements meant that interreinforcer intervals varied between 30 and 35 s. For this reason, in Conditions 2 and 3 responding was recorded only for the initial 30 s of a cycle.) As

Table 2

The sequence of conditions, numbers of sessions in each condition, and the percentage efficiency in each condition for each animal in Experiment 2. Figures in parentheses are standard deviations of the session means for the percentage efficiency.

Condition	R44		R45		R46	
	No. of sessions	Efficiency (%)	No. of sessions	Efficiency (%)	No. of sessions	Efficiency (%)
100%	32	79 (6.2)	23	93 (6.1)	23	90 (1.8)
80%	19	92 (7.2)	15	88 (6.2)	14	98 (1.6)
60%	15	84 (12.4)	17	97 (1.5)	16	97 (2.4)
40%	16	98 (2.8)	16	94 (2.4)	16	86 (10.4)
20%	24	90 (8.4)	16	96 (3.8)	15	87 (4.4)
10%	34	86 (4.0)	24	94 (2.1)	25	91 (3.6)
0%	21	85 (4.0)	22	94 (2.9)	22	94 (3.9)
20%	15	85 (6.1)	12	90 (5.4)	13	91 (4.3)

Figure 1 indicates, the pattern of responding for F2 and F3 resembled that normally found on an FI schedule. For 4 of the animals, the obtained percentages of programmed zero-delay reinforcements were comparatively low (8% for F7; 11% for F5; 14% for F3; 16% for F2). For F8 and F6, however, over 30% of their reinforcements were programmed zero-delays (33% for F8; 36% for F6).

The introduction of Condition 3 had no systematic effect on overall response rates across animals (Figure 2, upper panels). The 2 animals that showed an increase in response rate (F2 and F8) exceeded the percentage of obtained zero-delays that occurred in Condition 2 (21% for F2; 37% for F8). For the other animals, there was a decrease in the production of zero-delays (1% for F5; 33% for F6; 9% for F3; 1% for F7). The pattern of responding remained similar to those recorded in Condition 2 for all animals except F5 and F7, whose performance resembled that in Condition 1 (Figure 1) and which obtained virtually no zero-delays. Postreinforcement pauses decreased below those in Condition 2 for F5, F2, F7 and F8; for F5 and F8, these durations were below the corresponding ones in Condition 1 (Figure 2, lower panels). Pause durations for F6 and F3 increased further in Condition 3.

DISCUSSION

The present results provide further evidence of the role of variables other than the interreinforcer interval in the organization of behavior under interval schedules. Replicating Keenan and Leslie's (1984) finding, rats

under a recycling conjunctive FT 30-s FR 1 schedule showed a pattern of responding that peaked in the middle of the interreinforcer interval. When some zero-delay response-reinforcer contiguities were added to this schedule, the PRP increased, the overall response rate increased, and the pattern of responding more closely resembled that seen under FI schedules. Although comparatively small, these effects generally persisted when a relatively low maximum was set on the number of zero-delay reinforcements that could occur.

These findings indicate that response-reinforcer contiguity may play an important role in determining both overall response rates and the organization or distribution of responding within interval schedules, and they suggest that occasional contiguity may alter the pattern of responding from pause-respond-pause to an FI-like "scallop." However, the degree of scalloping was limited, and other studies of conjunctive schedules have apparently demonstrated the opposite effect and found that the occurrence of occasional contiguities is important for the maintenance of the pause-respond-pause pattern (Barrett, 1975, 1976; Katz & Barrett, 1979; Zeiler, 1976). The next experiment evaluated more precisely the effect of this variable by systematically manipulating the percentage of programmed zero-delay reinforcements. The complex procedure of Experiment 1, where responding was required in the initial 10 s of a cycle if contiguity was to be possible, was abandoned. Instead, a first response anytime within the first 30 s resulted in zero-delay response-reinforcer contiguity at the end of the cycle being set up

with some probability. This probability was varied across the conditions of the experiment.

EXPERIMENT 2

METHOD

Subjects and Apparatus

Three experimentally naive, 9-month-old, male hooded rats were used. They were maintained under the same conditions as those in Experiment 1. The apparatus of the previous experiment was used.

Procedure

Table 2 presents the sequence of conditions and the numbers of sessions in each condition. After they were trained through reinforcement of successive approximations to lever press, with sucrose as the reinforcer, animals were transferred to a modified recycling conjunctive FT 35-s FR 1 schedule of reinforcement (100% condition). In this condition, sucrose was presented at the end of a 35-s cycle if at least one response had been made in the first 30 s of that cycle. If a response occurred in the initial 30 s of a cycle, a subsequent response in the terminal 5 s of that cycle produced zero-delay reinforcement with a probability of 1.0 and terminated the cycle. As in the previous experiment, no other stimuli were presented when cycles ended without reinforcement. Responding was considered stable in each condition if it met the same criteria as were used in the previous experiment (see Table 2).

In the next condition, the 80% condition, the probability of a subsequent response in the terminal 5 s of a cycle producing zero-delay reinforcement was decreased to .8. If the first response in the terminal 5 s did not produce reinforcement immediately, further responses were rendered ineffective and the reinforcer was delivered at the end of the 35-s cycle.

In the conditions following, the probability of a subsequent response obtaining zero-delay reinforcement was systematically decreased (see Table 2). The final condition of the experiment was a repetition of the 20% condition. Note that in all conditions a response in the first 30 s of a cycle was sufficient to produce a reinforcer at 35 s on every occasion. Only the possibility of zero-delay reinforcement was varied.

RESULTS

The results presented here for each animal are the means calculated over the last five sessions in each condition. Overall response rates in each condition are presented in Figure 3 (left-hand panels). In the 100% condition, rates were between 19 and 30 responses per minute and these increased gradually towards a peak in the 60% condition for R45, and in the 80% condition for R44 and R46. Thereafter, response rates declined for all animals with the minimum rates obtained in the 0% condition. Rates increased again for all animals when the 20% condition was reintroduced. The right-hand panels of Figure 3 show the post-reinforcement pauses for each animal. These were roughly constant across conditions. Figure 4 shows the pattern of responding following reinforcer delivery for each animal in each phase of the experiment. (Note that, as in the previous experiment, responding was recorded only in the initial 30 s of a cycle to obviate the problems caused by slight variability in the duration of the interreinforcer intervals.) Response patterns in each condition resembled those typically found on an FI schedule, but R44 and R46 showed less acceleration in the last three conditions and a decrease in rate in the last 5-s segment in the 0% condition.

Responding was also recorded during cycles that began without reinforcer delivery. Responding after reinforcer omission was at a higher rate for all rats in all conditions, but acceleration through the interval still occurred.

DISCUSSION

In striking contrast to the results of the previous experiment, the procedures used here consistently generated FI-like behavior. "Scalloped" responding developed in the initial condition when a response between 30 and 35 s was followed by immediate reinforcer delivery, and that pattern persisted in the later conditions, except in some cases when that relationship obtained on only 20% of occasions or less. In Experiment 1, initial exposure to a recycling conjunctive schedule without explicitly arranged response-reinforcer contiguity produced the pause-respond-pause pattern usually found (see Keenan & Leslie, 1984), and introducing low percentages of

Fig. 3. Left-hand panels: mean response rate during the last five sessions of each condition for each animal in Experiment 2. Bars indicate standard deviations of the session means. Right-hand panels: corresponding median postreinforcement pauses, in seconds.

contiguous food delivery (up to 37%) tended to shift behavior toward the FI pattern. It appears, then, that the development of scalloping is a function of the percentage of response-reinforcer contiguities that occur. However, the animal's experimental history seems also to be important; once the FI pattern has been established, it will tend to persist despite gradual reductions in the percentage of response-reinforcer contiguities. This is perhaps not surprising inasmuch as these schedules do not require any particular pattern of behavior for the reinforcement rate to be maintained (see Keenan & Leslie, 1984). In addition, scalloping could, in principle, have been opposed in Experiment 1 by the requirement for a response in the first 10 s of a cycle if contiguity was to be programmed.

Previous studies have indicated that the incidence of response-reinforcer contiguity may be a major determinant of overall response rate (Lattal, 1974; Morgan, 1970; Shull, 1970; Staddon & Frank, 1975). In accord with this finding, rates in Experiment 2 were considerably higher than those in Experiment 1. However, within Experiment 2, the effects of this variable on overall response rate appeared weak. The only consistent finding was that

Fig. 4. Mean number of responses in successive sixths of the 30-s cycle immediately after reinforcement, for each animal in each condition of Experiment 2.

rates were lowest in the 0% condition. Again, it is not clear to what extent this lack of effect is due to the order in which experimental conditions were presented.

As far as PRPs are concerned, the durations observed when overall response rates were highest were comparable to those obtained when rats were maintained on an FI

Table 3

The sequence of conditions, numbers of sessions in each condition, and the percentage efficiency in each condition for each animal in Experiment 3. Figures in parentheses are standard deviations of the session means for the percentage efficiency.

Condition	R23		R24		R25		R26	
	No. of sessions	Efficiency (%)	No. of sessions	Efficiency (%)	No. of sessions	Efficiency (%)	No. of sessions	Efficiency (%)
A: recycling conjunctive	25	78.3 (4.0)	25	88.9 (4.8)	25	83.0 (6.9)	25	93.5 (4.4)
B1: 2-s zero-delay period	29	86.0 (8.8)	30	96.5 (4.5)				
B2: 4-s zero-delay period					28	93.9 (6.0)	29	100.0 (0.0)
A': recycling conjunctive	34	81.7 (5.5)	32	93.0 (2.6)	32	80.6 (4.6)	33	88.3 (6.5)
B1': 2-s zero-delay period			34	95.5 (4.9)	46	86.0 (1.6)	38	99.4 (0.5)
B2': 4-s zero-delay period	54	94.0 (2.0)						

30-s schedule of reinforcement (Lowe & Harzem, 1977). This observation suggests that the one major difference between the contingencies of the modified recycling conjunctive schedule used here and those of an FI schedule is relatively unimportant. The difference in question is that under an FI schedule, "very long pauses" (i.e., those exceeding the specified interval value) are invariably followed by immediate reinforcer delivery, whereas under a recycling conjunctive schedule this is extremely unlikely. It would appear, then, that the "regenerative" role often assigned to this feature of an FI schedule (see Zeiler, 1977) is not necessary to maintain moderate rates of responding.

In Experiment 2, responding in those intervals that began without reinforcer delivery was consistently at a higher rate than responding in intervals that began with reinforcer delivery. In addition to demonstrating the suppressive effects of reinforcer delivery (Staddon, 1974), these results are in agreement with other findings. Lowe and Harzem (1977), for example, found that rats' running rate under FI schedules was an increasing function of the preceding PRP. In view of this, it is not surprising that higher rates were recorded here in intervals beginning without reinforcer delivery because this responding occurred after pauses exceeding the FT component of the previous interval.

EXPERIMENT 3

It is not clear whether the differences in the results of Experiments 1 and 2 are due to differences in the percentages of zero-delay reinforcements obtained or to the animals' experimental histories, or even to minor procedural variations. Experiment 3 was designed to resolve this point by attempting reversals between conditions in which large numbers of programmed zero-delays were present and absent. In addition, a procedure was used that deviated somewhat less from the basic FT 30-s FR 1 schedule. Following initial training on the recycling conjunctive schedule, zero-delay reinforcers were introduced by presenting the reinforcer immediately following the first response within either the final 2 s or the final 4 s of the 30-s cycle.

METHOD

Subjects and Apparatus

Four experimentally naive, 6-month-old, male hooded rats were used. They were maintained under the same conditions as those described in Experiment 1. The apparatus of the previous experiments was used.

Procedure

The sequence of conditions and the numbers of sessions for each animal in each condition are given in Table 3. For all rats, lever

Fig. 5. Numbers of zero-delay reinforcements (dashed lines) and response rates (solid lines) from the last five sessions of the original baseline training and the remainder of Experiment 3.

pressing was established by reinforcement of successive approximations and was then maintained on a recycling conjunctive FT 30-s FR 1 schedule (Condition A). Sessions were conducted daily and the stability criterion used was the same as that used in the previous experiments. In all conditions, a session began with the delivery of a response-independent reinforcer and it terminated when a further 100 reinforcers had been obtained.

Following Condition A, 2 rats were assigned to Condition B1 and 2 to Condition B2. In Condition B1 the normal recycling conjunctive contingencies applied throughout the FT component. In addition, the first response occurring in the final 2 s of the FT component produced a reinforcer immediately (zero-delay reinforcement) and terminated the cycle. Note that this contingency operated whether or not responses had occurred in the earlier part of the FT component. If a response did not occur in the final 2 s of the 30-s cycle, but had occurred earlier, then a rein-

forcer was delivered at the end of 30 s. Condition B2 was the same as B1, except that zero-delay reinforcements followed the first response within the final 4 s of the FT component.

When its performance had stabilized in Condition B1 or B2, the rat was transferred back to the recycling conjunctive schedule used originally (Condition A') and was maintained on that until stability was obtained. The stability criterion used for each condition was the same as that described in Experiment 1.

In the final phase of the experiment, the animals previously exposed to Condition B2 (R25 and R26) were exposed to Condition B1. Rat R23, previously exposed to B1, was trained on B2; Rat R24, previously exposed to B1, was returned to that condition (B1'). The reason for not using the alternative schedule for this rat is explained below.

In the baseline conditions (A and A'), the delays between the last response and reinforcer delivery were recorded. Those less than 0.5 s

Fig. 6. Local rates of responding under baseline conjunctive schedules (A and A') and schedules with programmed zero-delay reinforcements (B1, B1', and B2) for 2 rats in Experiment 3.

Fig. 7. Local rates of responding under baseline conjunctive schedules (A and A') and schedules with programmed zero-delay reinforcements (B1 and B2) for 2 rats in Experiment 3.

were designated as zero-delays for purposes of comparison with Conditions B1 and B2 where programmed zero-delays could occur.

RESULTS

Figure 5 shows the numbers of zero-delay reinforcements and the overall response rates for the last five sessions of the original baseline condition (Condition A') and for each subsequent session of the experiment. Rates of responding and numbers of zero-delays were

relatively low in Condition A, and they increased substantially for 3 rats in Condition B1 or B2. Each of those 3 subjects eventually showed numbers of zero-delays close to 100, the maximum possible. The fourth subject (R23) showed no appreciable change in either measure in Condition B1. On return to baseline (Condition A'), the original behavior was recovered. In the final part of the experiment, again 3 of 4 rats showed dramatic changes in behavior. The rat that showed no change un-

der B1 (R23) eventually changed under B2. The rat that previously responded under B1 (R24) was tested again on this condition (B1') because of the remarkable effects produced by this relatively stringent procedure.

The 2 rats previously trained on B2 were now trained on B1 and one (R26) showed corresponding changes in behavior. In summary, all 3 rats trained on a schedule in which responses occurring in the last 4 s of a cycle were followed by zero-delay reinforcement showed a marked increase in response rate and eventually obtained zero-delay reinforcement on almost 100% of occasions. Of 4 rats trained on a schedule with a more stringent criterion, one that ensured zero-delays only for responses occurring in the last 2 s of a cycle, 2 showed changes in behavior and 2 behaved as if still on the baseline schedule where no zero-delay reinforcements were programmed. There was no systematic effect on postreinforcement pauses, which remained at approximately 16 s across conditions for each animal.

Patterns of behavior under the various schedules are shown in Figures 6 and 7. Under baseline training (A and A'), 3 rats showed a peak in the middle of the interval, and the fourth (R24) showed a slowly increasing rate over the second half of the cycle. On those occasions when Condition B1 or B2 increased response rate and number of zero-delay reinforcements, the patterns of responding showed a corresponding change to a scalloped pattern with a high rate at the end of the cycle. Note that curves for B1 and B2 terminated at 28 s and 26 s, respectively.

Final stable performances showed that, given sufficient opportunities for zero-delays, the response pattern shifted to one like that generated by an FI schedule. To illustrate the way in which this came about, Figure 8 shows patterns of responding on the last original baseline session (Condition A) and the third, sixth, and ninth session of the first zero-delay condition. (One animal, R23, is excluded, as its behavior did not change with this transition.) There is evidence of systematic changes in performance in all 3 rats. For R26, the decline in responding in the latter part of the interval was reversed, until by about the ninth session, responding was maximal in the final 7 s of the interval. For R24 and R25, however, the increase in response rate across ses-

sions appeared as an increase in responding in both the middle and latter parts of the cycle. Figure 9 presents similar data for the 3 rats whose behavior changed in the second transition from the baseline conjunctive schedule to the one with programmed zero-delays. (Data are presented for more widely spaced sessions for R23 because this animal's performance changed more slowly.) By the third session for R24, the change in performance was qualitatively similar to that observed for this rat after the previous transition to a schedule with programmed zero-delays. Thereafter, however, responding increased dramatically in the last 6 s of the interval. The major changes for the other 2 animals were an increase in responding in both the middle and latter parts of the interval for R26, but an increase in responding only in the latter half of the interval for R23. In summary, when Figures 8 and 9 are considered together, there is evidence of initial changes in responding either in the middle or at the end of the interval. Note that in the results shown in these two figures, performance had not reached anywhere near the final levels shown in Figures 6 and 7. Thus the steady increases in response rate late in the interval continued over many sessions and obscured any further increases in responding in the middle of the interval.

GENERAL DISCUSSION

Recycling conjunctive schedules generated a pause-respond-pause pattern with the distribution of responses tending to peak at mid-interval. The addition of a sufficient number of zero-delay response-reinforcer contiguities altered this pattern, producing the "scallop" characteristic of FI performance. Experiment 1 showed that with low numbers of zero-delays the pause-respond-pause pattern was only slightly modified. In Experiment 2, initially high levels of zero-delays generated FI-like behavior that persisted as zero-delay reinforcements were gradually reduced in probability. In Experiment 3, the introduction of the opportunity for a high percentage of zero-delay reinforcements produced a transition to FI-like behavior, and the removal of such zero-delay contiguities produced a return to the pause-respond-pause pattern. Overall response rates generally varied with the num-

Fig. 8. Local rates of responding in the final session of baseline conjunctive schedule (A) and in selected sessions early in training with programmed zero-delay reinforcements (B1 and B2).

ber of zero-delay reinforcements. This effect was small in Experiment 1, moderate in Experiment 2, and considerable in Experiment 3 where large differences occurred in the numbers of zero-delay reinforcements in successive experimental conditions. Postreinforcement pauses, however, did not vary with number of zero-delay reinforcements, and in Experiments 2 and 3 they were highly consistent across conditions.

The aim at the outset of these experiments was to develop a procedure that could be used to examine the effects of introducing contiguity to a schedule constructed from a combination of FT and FR 1 components. Until now, only FI, conjunctive, and recycling conjunctive schedules have been available, and we have already noted how the differing dynamic interactions inherent in the structural diversity of these schedules make it difficult to draw

Fig. 9. Local rates of responding in the final session of the second baseline schedule (A') and in selected sessions early in training with programmed zero-delay reinforcements (procedures B1' and B1 for Rats R24 and R26, respectively, and procedure B2 for Rat R23).

any decisive conclusions about the contribution of response-reinforcer contiguity to performance. The main advantage of the present procedures, particularly the procedures described in Experiment 3, is that they permit the effects of contiguity to be assessed without added complications incurred from other major changes in the nature of the response contingency. Also, there is no interference with "spontaneous regulation" on the schedule (see Neuringer & Schneider, 1968).

The results are in accordance with our general thesis that schedule performances are explicable in terms of a relatively small set of general principles. These principles, however, will be elucidated only if the various factors contributing to well known and apparently "simple" schedule performances are disentangled. A number of conclusions are evident: (1) The manner in which an FR 1 requirement is added to an FT schedule is a crucial determinant of the behavior observed. (2) If the schedule is arranged so that few response-reinforcer contiguities are likely, a pause-respond-pause pattern develops. (3) When a sufficient percentage of response-reinforcer contiguities are arranged, an FI-like pattern of behavior emerges. (4) Postreinforcement pauses do not change correspondingly. Thus the duration of the PRP and the amount and patterning of responding are controlled by different factors (cf. Neuringer & Schneider, 1968; Shull, Guilkey, & Witty, 1972).

It has been suggested previously that the pause-respond-pause pattern seen under conjunctive schedules results from occasional response-reinforcer contiguity following long pauses (Katz & Barrett, 1979; Zeiler, 1976). In the present study, as in that of Keenan and Leslie (1984), however, pause-respond-pause patterns were maintained on recycling schedules without such contiguities occurring. This would suggest that it is the variability in the response-reinforcer delays that occurs on conjunctive schedules that is responsible for the pause-respond-pause sequence. Inasmuch as lever pressing is unlikely to be a terminal behavior pattern in rats (Davis & Hubbard, 1972), other patterns may intervene between the designated response and reinforcer delivery and so constitute the terminal "pause." (Given the demonstration of the dramatic effects that response-reinforcer contiguity can have, it is also conceivable that similar effects operate on other activities to determine the

nature of the behavior during the terminal pause.)

Where contiguity has clearly been shown to play an important role is in the strengthening of a previously established pattern of behavior. This can be seen in those conditions of Experiment 3 in which contiguity was increased. There, the response-strengthening effect of contiguity operated initially by increasing the vigor or persistence of the existing pattern of responding. That is, responding began at the same point within the interreinforcer interval as under the unmodified recycling schedule, but it tended to occur at a higher rate or to persist until later in the interval (see Staddon & Frank, 1975). With further increases in contiguity, the pause-respond-pause pattern was abolished and supplanted by FI-like responding. Thus, the response strengthening effects of contiguity are directly implicated as an important determinant of FI performance (see Keenan & Leslie, 1984; Nevin, 1982).

In Experiment 3, the recovery of the pause-respond-pause pattern contrasts with the persistence of FI-like patterning when low percentages of zero-delay reinforcements were programmed in Experiment 2. Whether or not this discrepancy is a result of the prolonged exposure to relatively high percentages of zero-delay reinforcements in Experiment 2 remains to be determined. Other experiments are also needed to assess whether the transition to FI-like performance in Experiment 3, which was initiated by a relatively small percentage of programmed zero-delay reinforcements, would have continued if the percentage of programmed zero-delay reinforcements had been limited to between 20 and 30%. It may be that other fortuitous contiguities arising from an increase in responding under these circumstances would help to sustain a continued increase in responding. If this was the case, it would have important implications for the analysis of performance on FT schedules.

The findings reported here, along with those described by Fenner (1980), argue against the notion that contingencies simply select from among activities that are facilitated by temporal proximity to food (Staddon & Simmelhag, 1971). The combination of variables on a number of schedules may be nominally similar, but we have argued that it is the manner in which they interact that determines their relative contributions to the control of behavior.

ior. This poses problems for the design of suitable procedures to determine the contribution of response-reinforcer contiguity to performance on FT schedules. We have already noted one of the difficulties with using an FI schedule for comparison purposes with an FT schedule (i.e., the F-RD interval is confounded with the duration of the interreinforcer interval). But perhaps the greatest difficulty is in achieving an appropriate degree of control over response-reinforcer contiguity. This problem is more acute when, as in the majority of published studies, pigeons are used as subjects. Pecking frequently occurs as terminal behavior of pigeons exposed to FT schedules of food delivery (Staddon & Simmelhag, 1971), and it is possible that the occurrence of response-reinforcer contiguities during this exposure contributes importantly to the production of FI-like behavior (see Lowe & Harzem, 1977). In view of the powerful effects of contiguity reported here, we would suggest that future studies with FT schedules should record the actual frequencies of response-reinforcer contiguities for a number of responses. It might be possible to examine also the effects of manipulating the relative frequencies of these response-reinforcer contiguities in a manner similar to that described here. Without the appropriate information, accounts of performance on FT schedules will continue to remain rather speculative.

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