*SEPARATING RESPONSE DEPENDENCY AND
RESPONSE-REINFORCER CONTIGUITY WITHIN
A RECYCLING CONJUNCTIVE SCHEDULE*

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A procedure is described which disrupts response-reinforcer contiguity and response dependency and which demonstrates how the location of the response dependency in interval schedules can be regarded as a controlling variable in its own right. Rats' lever pressing produced sucrose on a recycling conjunctive fixed-time 30-second fixed-ratio 1 schedule of reinforcement. Reinforcement occurred only at the end of the fixed-time component on this schedule and only if a response had occurred during that component. This produced a pause-respond-pause pattern during the interreinforcer interval for all animals. When the location of the response dependency was then restricted to a 10-second period in the middle of the fixed-time component, the pattern was accentuated and response rates increased for all animals, while postreinforcement pauses decreased sharply for two animals. When responding was required in the first 10 seconds of the fixed-time component, responding peaked earlier in the interval for all animals. Response rates were slightly below those in the previous conditions, while postreinforcement pauses were between 2 and 6 seconds across animals.

Key words: conjunctive schedule, response dependency, contiguity, terminal behavior, lever press, rats

The contingencies that define a fixed-interval (FI) schedule of reinforcement not only ensure contiguity between a response and every reinforcer but also result in a relatively fixed interreinforcer interval. Whether or not responding on this schedule is best characterized as "break and run" (Cumming & Schoenfeld, 1958) or as a "scallop" (Dews, 1978), the temporal placement of the reinforcing event contributes to the stereotypic effect of the schedule (Zeiler, 1977). Accordingly, Anderson and Shettleworth (1977) assert:

Pavlovian temporal conditioning plays a large role in determining the behavior animals exhibit when reinforcers are delivered at predictable times, and . . . response contingencies simply select from among activities that are facilitated by conditioned anticipation of the reinforcer. (p. 46)

In their experiment, which compared the performance of hamsters on both FI and fixed-

time (FT) schedules, Anderson and Shettleworth found that lever pressing occurred as a terminal activity only if a contingency specified that lever pressing was necessary for food production. Thus, in addition to the temporal distribution of reinforcers obtained on an FI schedule, the nature of the required response is also an important factor.

On most schedules the response requirement determines the type of behavior occurring just before reinforcer delivery, and this can be seen as one of the ways in which a schedule limits the variation in behavior that can occur. On an FI schedule, for example, in which the location of the response requirement is restricted to the end of the interreinforcer interval, it is inevitable that the selected operant appears as the predominant terminal activity. This conclusion draws attention to an important feature of an FI schedule that has received little attention—namely, the requirement to make a response at some time interval after food. This requirement is embedded in the formal specifications of the schedule and it may well be a controlling variable in its own right.

To appreciate this more clearly it is helpful to conceptualize an FI schedule as a tandem FT FR 1 schedule of reinforcement (after Zeiler, 1968). If all that were important in maintaining responding on this schedule were

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the temporal distribution of reinforcers and the requirement to make one response for each reinforcer, then it should not matter where this requirement is located so long as the temporal regularity is maintained. One way to examine this is to use a schedule that permits the FR component to be completed either before or after the FT component expires. A conjunctive schedule is such a procedure. For example, if a response occurs on a conjunctive FT FR 1 before the FT component expires, then the reinforcer is delivered at the end of the FT component. If, however, the FT component terminates before a response is made, then the reinforcer is presented dependent upon the first response.

Such conjunctive schedules do not maintain the same behavior patterns as FI schedules. Response rates maintained by an FI schedule are appreciably higher than those maintained by its conjunctive counterpart, and the characteristic patterning on an FI schedule is replaced by a pause-respond-pause pattern during the interreinforcer interval of the conjunctive schedule (Morgan, 1970; Powers, 1968; Shull, 1970). Studies which have manipulated the size of the ratio component on the conjunctive FT FR schedule reveal that the pause-respond-pause pattern is retained and that total number of responses and pause duration are sensitive to the value of the ratio component (Zeiler, 1976). Similar effects have been reported with conjunctive FI FR schedules (Zeiler & Buchman, 1979), and on both conjunctive schedules the duration of the interval component has little effect on pause duration or number of responses per reinforcer. However, the nature of the interval component does affect the overall pattern of responding (Barrett, 1975).

The pattern of responding described here for conjunctive schedules is in sharp contrast to what might have been expected under a schedule in which the interreinforcement time is more or less constant (Dews, 1970). To account for this, Herrnstein and Morse (1958) speculated on the role of possible "dynamic interactions" operating on the schedule. They suggested that the initial rate of responding, which resembles performance on a simple FR schedule, might result from the value of the FR component acquiring discriminative control through repeated instances of the interval lapsing without a response and food being

delivered immediately after the ratio is completed. More recent studies that have either prevented the FR from acquiring discriminative properties (Barrett, 1976; Katz & Barrett, 1979) or have increased its discriminability (Barrett, 1975; Zeiler, 1976) provide evidence to support this analysis. In the former studies, the procedures used precluded the development of typical conjunctive patterning, but in the latter studies the patterning was found to be accentuated.

If we return now to our initial concern with the nature of the response dependency in interval schedules, we can see that the location of the response dependency greatly affects the behavior observed by defining the bounds of possible response-reinforcer interactions. In other words, the dynamics of a schedule are limited by the formal specifications of the schedule.

Earlier we considered the possibility that the location of the response dependency on an FI schedule could be conceptualized as a controlling variable, and that conjunctive schedules could be used to manipulate this variable. The procedures developed here implement this idea and are based on a schedule first described by Staddon and Frank (1975). They trained pigeons on a "recycling" version of the conjunctive FT FR 1 schedule of reinforcement in which the response requirement was located within the FT component. Reinforcement occurred at the end of the FT component if at least one response was emitted during that component, but if a response was not made during an FT component, that component ended without reinforcement and the next one began immediately. On this schedule, pauses exceeding the duration of the FT component were not followed by response-reinforcer contiguity, as would be the case on the usual conjunctive FT FR 1. This basic procedure was repeated in the present study with rats and was then modified to examine the effects of restricting the location of the response dependency still further. This was done by requiring the response to be made in either the first or second third of each FT component.

METHOD

Subjects

Three experimentally naive, 6-month-old, male hooded rats were used. They were caged

Table 1

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

Condition	Procedure	Rat Number					
		F1		F5		F6	
		No. of Sessions	Efficiency (%)	No. of Sessions	Efficiency (%)	No. of Sessions	Efficiency (%)
1	Recycling conjunctive FT 30-s FR 1	20	90 (4.1)	22	83 (8.6)	20	83 (8.0)
2	Recycling conjunctive + response dependency in the middle 10 s of cycle	38	87 (6.5)	33	78 (4.6)	28	83 (5.6)
3	Recycling conjunctive + response dependency in the first 10 s of cycle	31	77 (5.8)	31	66 (5.6)	28	62 (6.4)
4	Recycling conjunctive + response dependency in the middle 10 s of cycle	27	75 (8.2)	44	73 (6.7)	27	75 (8.2)
5	Recycling conjunctive			15	82 (2.0)	32	85 (4.5)

singly with water freely available and were maintained at approximately 80% of their free-feeding body weights by feeding after experimental sessions. One animal (F1) died before completing the final condition of the experiment.

Apparatus

A standard Campden Instruments rat test chamber (Model CI 410) was used. The reinforcing stimulus consisted of 5-s access to 0.1 ml of 5% sucrose solution (by weight) delivered into a recessed tray situated 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 Nova 2 digital computer programmed contingencies and collected data.

Procedure

The sequence of conditions and the number of sessions in each condition are given in Table 1. After lever pressing was handshaped with sucrose as reinforcer, the animals were transferred to a recycling conjunctive FT 30-s FR 1 schedule of reinforcement (Condition 1). In this condition one response at any time during a 30-s cycle produced sucrose at the end of that cycle (see Figure 1). Failure to respond in any cycle meant that that cycle ended without sucrose and the next cycle began immediately. For each condition, animals received one session daily, each session terminating after 100

Fig. 1. A schematic representation of the procedures used in each condition. The location of the response dependency in each 30-s cycle is indicated by the shaded area. One response was required in the shaded area of each cycle to produce reinforcement at the end of that cycle.

reinforcers. Given that at least one response was required during an FT component, a straightforward measure of performance efficiency is the total number of reinforced cycles expressed as a percentage of the total number

of cycles in a session. Performance was considered stable when this measure remained fairly constant and above 70% (see Table 1). This stability criterion was used for all conditions, except Condition 3 in which it was relaxed to 60%.

In Condition 2, one response at any time during the middle 10 s of a 30-s cycle produced reinforcement at the end of that cycle. Failure to respond in this period meant that that cycle ended without reinforcement and the next cycle began immediately.

In Condition 3, one response in the first 10 s immediately after the start of a cycle produced reinforcement at the end of the cycle. As in the previous conditions, failure to meet the schedule requirement resulted in the omission of reinforcement at the end of the cycle, and the next cycle began immediately. Condition 4

was the same as Condition 2, and Condition 5 was the same as Condition 1.

RESULTS

The results presented here for each animal are the means calculated over the last five sessions in each condition. Figure 2 shows the overall response rates (upper panel) and median postreinforcement pauses (PRP) (lower panel) recorded in each condition. Response rates were lowest under Condition 1, varying between five and twelve responses per minute. The introduction of Condition 2, in which a response had to occur in the middle 10 s of the FT component, resulted in the highest response rates observed for all animals. When the response dependency was located in the 10 s immediately after the start of a cycle

Fig. 2. Upper panels: The mean response rate during the last five sessions of each condition for each animal. Bars indicate one standard deviation of the session means. Lower panels: The median postreinforcement pause (s) in each condition for each animal.

(Condition 3), there was a slight decrease in responding across animals. Response rates following the introduction of the next two conditions (Conditions 4 and 5) decreased to levels below those recorded initially with each of these procedures.

In Condition 1 the median PRP, measured to the first response after reinforcement, varied between 8 and 12 s across animals. Postreinforcement pauses decreased for F1 and F5 in Condition 2; the shortest PRPs observed for all animals were in Condition 3. In Condition 4, PRPs increased over those in Condition 3, although they were only restored to the previous level with this procedure for F5. Pause durations were further increased for F5 and F6 in Condition 5.

Figure 3 gives the rate of responding as a function of time since reinforcement. Responding in Condition 1 was most rapid in the middle of the 30-s cycle, and this is reflected in the pause-respond-pause pattern evident on the cumulative records in Figure 4. This rapid responding in the middle of the cycle was accentuated by the introduction of Condition 2. In the next condition (Condition 3), a shift in response distributions was observed with responding peaking early in the cycle for all animals and decreasing slowly towards the end of the cycle. The patterns of responding produced by Condition 4 were similar to those produced initially with this procedure (Condition 2). In Condition 5, response distributions differed from those recorded initially (Condition 1) in that relatively more responses occurred early in the cycle and fewer responses occurred later in the cycle.

Figure 5 shows the distribution of PRPs less than 30 s in all conditions of the experiment. In Condition 1, between 21% and 56% of PRPs were of less than 10-s duration. With the introduction of Condition 2, over 60% of pauses occurred in the first 10 s of the cycle for all animals. This value was further increased to between 70% and 80% in Condition 3. In Conditions 4 and 5 the percentage of short PRPs remained somewhat above those produced initially with these procedures, especially in the latter case.

DISCUSSION

The ability of conjunctive schedules to maintain responding that is temporally re-

Fig. 3. The mean numbers of responses in successive sixths of the 30-s cycle immediately after reinforcement for each animal in each condition.

moved from the occurrence of the reinforcer has been traced to the occasional immediate reinforcement of responding (Barrett, 1976; Katz & Barrett, 1979). A related finding by Staddon and Frank (1975) was the higher over-

Fig. 4. Sample cumulative records for each animal in Conditions 1, 2, and 3. Reinforcer deliveries are indicated by downward deflections of the pen.

all rates obtained on the conjunctive FT FR than on the present, recycling version of this schedule. They attributed this difference to the facilitative effects of occasional peck-food contiguities that were more probable at long post-food times on the normal conjunctive than on the recycling schedule. The recycling conjunctive FT FR 1 used here with rats also produced very low response rates. However, the highly efficient performance of these animals contrasts with the relatively inefficient performance of the pigeons used by Staddon and Frank. Also, the pause-respond-pause pattern that appeared in Condition 1 persisted throughout all conditions, with the durations of the initial pause decreasing systematically as responding was required earlier in the FT component. In view

of the scepticism with which Staddon and Frank viewed the possible outcome of the recycling procedure, these findings are a remarkable demonstration of behavioral control without the supportive effects of explicitly available contiguity between the operant response and the reinforcer. It must be remembered, however, that fortuitous contiguities were possible throughout each of the conditions and these may have contributed to the performances obtained.

Although patterns like the present ones have been observed before on conjunctive schedules (e.g., Shull, 1970), it has been suggested that they are not attributable to the conjunctive contingency per se but merely reflect a characteristic of responding under periodic food de-

Fig. 5. The distribution of postreinforcement pauses less than 30 s as a percentage of the total number of pauses less than 30 s for each animal in each condition.

livery when response strength is low (Staddon & Frank, 1975). Given, however, that each component of a conjunctive schedule has been shown to contribute to the development of patterning, and that FI and FT components produce different patterns after the conjunctive ratio component has been completed (Barrett, 1975), the patterns observed here may have been due to the presence of an FT contingency. Casual observations of the animals in this study support this conclusion because terminal pausing was found to consist mainly of food-tray-oriented activities. These are precisely the responses that rats emit when exposed to FT schedules (Lowe & Harzem, 1977).

Because these responses were evident throughout the experiment, an interesting question arises: Is lever pressing "displaced" from the end of the interval because it is not a terminal activity or simply because it is the required operant response? It might be that inasmuch as lever pressing is not required at the end of the interval, as it would be in an FI schedule, it is replaced by a terminal behavior pattern. Or, intriguingly, it may be a terminal behavior pattern but the nature of the conjunctive schedule may lead to other terminal patterns occurring at the end of the interval. The possibility that it is terminal behavior—the location in time of which is determined by the dynamics of the reinforcement contingency—is strengthened by the findings of Leslie, Boakes, Linaza, and Ridgers (1979). In a study of autoshaping in rats, they found that rats would approach and press an illuminated plastic lever that signaled food delivery.

Normally, on a schedule of reinforcement there is a close and consistent temporal proximity between the occurrence of a response and the delivery of a reinforcer. As a result of this, the location of the reinforced response and the time at which the reinforcer is available are confounded. On an FI schedule, the confounding of contiguity and the location of the response dependency has led to the conclusion that the response under consideration is primarily organized with respect to the location of the reinforcer. However, the present procedures, developed to unconfound these two variables, support a different interpretation. They suggest that the interreinforcer interval of an FI schedule may be usefully separated into two intervals: the food-food (F-F) interval that refers to the time between reinforcer

presentations, and the interval between food and response dependency (F-RD) that refers to the time between one reinforcer presentation and the location of the next response dependency. Of these, the F-RD interval should be regarded as the main determinant of pausing and response patterning. One might suggest that the F-RD interval of an FI schedule has response shaping effects and that response-reinforcer contiguity has response strengthening effects. This analysis, then, calls for an exhaustive appraisal of the relative contribution of three variables to performance on FI schedules—that is, the F-F interval, the F-RD interval, and response-reinforcer contiguity.

Finally, the emphasis usually placed on the temporal processes associated with the highly regular and periodic presentation of food reinforcement has been shown to be of limited explanatory value in accounting for either the performances shown here or those found under various other conjunctive schedules (e.g., Zeiler & Buchman, 1979). Richelle and Lejeune (1980) reached similar conclusions when comparing various time-based schedules and asked: Is there a "common unifying timing device underlying all of them, or are there as many timing mechanisms as there are different types of temporal regulation?" (p. 82). What is needed to answer this question is a more precise examination of the structural intricacies of contingencies that generate temporally regulated behavior.

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