DEPENDENCY, TEMPORAL CONTIGUITY, AND RESPONSE-INDEPENDENT REINFORCEMENT

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A comparison was made of the effects of variable-interval, variable-time, and tandem variable-interval fixed-time schedules on key-peck responding of pigeons. The variable-interval component of the tandem schedule retained the response-reinforcement dependency; the fixed-time component allowed the temporal proximity between responding and reinforcement to vary, constrained only by the duration of the fixed-time interval. Response rates were highest during the variable-interval and lowest during the variable-time schedule. Intermediate response rates occurred during the tandem schedule. The results of a yoked control condition showed that the effects of the tandem schedule were not due simply to changes in reinforcement distribution or frequency. The results suggest that substantial reductions in responding occur when reinforcement is response-dependent but not necessarily contiguous with the response required to produce reinforcement.

Key words: variable-interval schedules, variable-time schedules, tandem schedules, unsignalled delay of reinforcement, response-independent reinforcement, temporal contiguity, dependency, key pecking, pigeons

A dependent relation exists between behavior and an environmental event if the event, "must, by nature of the situation, occur following the behavior" (Reynolds, 1975, p. 34). Although the terms dependency and contingency are frequently used interchangeably, a contingent relation (*e.g.*, temporal contiguity) is not necessarily implied in the definition of dependency (Reynolds, 1975, p. 34; Zeiler, 1972). The terms response-dependent and response-independent reinforcement describe operations in which a particular response is necessary or irrelevant for the delivery of a reinforcer.

In its conventional usage, the dependency specifies the response that is temporally contiguous with reinforcement, *i.e.*, delivery of the reinforcer. Response-independent reinforcement is also contiguous with some response but the characteristics of the response are not specified by a dependency. Transitions from response-dependent reinforcement schedules, in which food delivery is contiguous with the measured response, to response-independent reinforcement schedules are characterized by reductions in response rates, sometimes to

zero (*e.g.*, Herrnstein, 1966; Zeiler, 1968). In such studies, the removal of the response-reinforcer dependency is presumably accompanied by a change in temporal contiguity between the measured response and reinforcement, although supporting data have not been systematically reported. While such effects are correctly attributed to the operation of removing the response-reinforcement dependency, a more refined experimental analysis seems invited in order to isolate the behavioral effects of changes in dependency and contiguity.

Both signalled and unsignalled delay of reinforcement procedures retain the response-reinforcement dependency while allowing changes in temporal contiguity between response and reinforcement. Signalled delay of reinforcement may be considered a chained schedule with response-independent reinforcement in the terminal link (Ferster, 1953; Ferster and Skinner, 1957, pp. 684-685). The unsignalled delay-of-reinforcement procedure, then, is an analogous tandem schedule. Ferster (1953) examined key pecking of pigeons during chained variable-interval 1-min fixed-time (chain VI 1-min FT) schedules in which the FT was either 60 or 120 sec. Initially, response rates during the VI component of the chained schedule decreased, but after repeated expo-

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sure to the delay procedures the rates increased and stabilized at a level below the nondelay baseline rates (*cf.* Chung, 1965). Some birds stopped responding, but, after a return to the VI schedule, subsequent gradual increases in the duration of the delay resulted in sustained responding by these birds. Skinner (1938) and Azzi, Fix, Keller, and Rocha e Silva (1964) studied an unsignalled delay-of-reinforcement procedure with rats in which each response during the delay interval restarted the interval, ensuring the specified delay between responding and reinforcement. Azzi *et al.* (1964) reported an inverse relation between delay duration and response rate. Dews (1960) maintained pigeons' responding in the initial link of a tandem fixed-ratio 1 fixed-time schedule in which the FT was 10, 30, or 100 sec. Unlike the Skinner and Azzi *et al.* studies, responding in the delay interval did not affect delivery of the reinforcer.

A number of methodological problems preclude direct application of these delay-of-reinforcement studies to an assessment of changes produced by variations in response-reinforcer contiguity while maintaining a constant dependency. In the signalled delay-of-reinforcement procedure, the stimulus presented during the delay interval may function as a conditioned reinforcer through its association with food. Behavior maintained in the initial link may therefore be attributed in part to response-dependent conditioned reinforcement, rather than to the dependency between the response and delayed food reinforcement. Dews' (1960) conclusions about unsignalled delay-of-reinforcement procedures were restricted by limiting the baseline schedule to FR 1. Dews also did not report FR 1 baseline response rates before introducing the tandem schedule and it is not possible to determine how the response rates during the tandem schedule changed from those obtained during FR 1. The procedures of Skinner (1938) and Azzi *et al.* (1965) are not directly applicable to the present problem because the differential-reinforcement-of-other-behavior (DRO) schedule is not a strictly response-independent procedure. Rather, that schedule specifies that a behavior other than the measured response must be contiguous with reinforcement. Additionally, the cited studies of both signalled and unsignalled delay of reinforcement confounded delay of reinforcement and frequency

of reinforcement by adding the delay at the end of the initial link.

The present experiment used tandem VI FT schedules to study the effects on key-pecking of removing the restriction of temporal contiguity between the measured response and reinforcement while retaining the dependency between them. These effects were compared to those that occurred during variable-interval and variable-time schedules.

METHOD

Subjects

Six adult White Carneaux pigeons were maintained at 80% (± 15 g) of their free-feeding weights. All subjects had a history of key pecking under several reinforcement schedules.

Apparatus

Two similar operant-conditioning chambers were used. The work enclosure of each chamber was 33 by 33 by 35 cm. A 2.5-cm diameter response key was mounted on the midline of each work panel, 23 cm above the floor. A force of approximately 0.10 N was required to operate the key in each box. Each key was transilluminated by a red light except during reinforcement. General illumination was provided by two lights located behind a 4-cm diameter white plastic disc. A grain hopper was located behind a 5-cm square aperture 13 cm below the response key. The aperture was illuminated with a white light during reinforcement, which was 3-sec access to grain in the hopper. White noise and a ventilation fan masked extraneous sounds. Scheduling and recording equipment were in a separate room.

Procedure

The key-peck responding of Birds 10, 33, and 61 was maintained with a VI schedule, the value of which was changed over several sessions to VI 63-sec. Table 1 shows the sequence of schedules and the number of sessions each was in effect for each bird. The initial sequence was a VI schedule, a VI schedule with an unsignalled delay of reinforcement procedure, and a VT schedule. Subsequent replications of the different schedules were included to verify the original findings and further to study contributions of other variables to the obtained behavior.

Figure 1 schematically illustrates each of

Table 1

Sequence of experimental conditions, number of sessions, and responses per minute for each experimental and yoked control subject. Mean delays between the last response and reinforcement for each experimental bird are also shown. All data are the average of the last six days of each condition.

<i>Bird 10</i>					
<i>Con- dition</i>	<i>No. of Ses- sions</i>	<i>Mean Delay (sec)</i>	<i>Resp per Min</i>	<i>Reinf per Min</i>	<i>Resp per Min (yoked control Bird 96)</i>
VI	15	—	42.3	0.95	—
VI delay	28	—	27.1	0.91	—
VT	20	—	14.0	0.95	—
VI delay	38	—	29.6	0.91	—
VI	—	—	—	—	—
VT	—	—	—	—	—
VI	45*	—	37.5	0.93	24.9
VI delay	54*	2.55	12.8	0.80	42.6
VT	32*	4.64	7.9	0.90	49.0
VI	17*	—	30.6	0.89	39.4
VI delay	13*	3.36	9.8	0.81	45.9

<i>Bird 33</i>					
<i>Con- dition</i>	<i>No. of Ses- sions</i>	<i>Mean Delay (sec)</i>	<i>Resp per Min</i>	<i>Reinf per Min</i>	<i>Resp per Min (yoked control Bird 24)</i>
VI	20	—	39.4	0.95	—
VI delay	16	—	14.3	0.88	—
VT	6	—	2.6	0.95	—
VI delay	13	—	30.6	0.91	—
VI	25	—	43.8	0.95	—
VT	32	—	21.3	0.95	—
VI	54	—	43.6	0.95	61.6
VI delay	62	1.0	26.0	0.90	78.9
VT	11	2.67	4.6	0.95	99.2
VI	10	—	47.0	0.95	100.5
VI delay	24	1.57	20.5	0.86	101.7

<i>Bird 61</i>					
<i>Con- dition</i>	<i>No. of Ses- sions</i>	<i>Mean Delay (sec)</i>	<i>Resp per Min</i>	<i>Reinf per Min</i>	<i>Resp per Min (yoked control Bird 84)</i>
VI	16	—	39.4	0.95	—
VI delay	14	—	14.5	0.89	—
VT	20	—	8.3	0.95	—
VI delay	15	—	8.4	0.85	—
VI	8	—	32.8	0.95	—
VT	30	—	4.0	0.95	—
VI	63	—	35.6	0.95	60.5
VI delay	55	1.99	9.3	0.86	58.0
VT	10	2.74	3.0	0.95	78.0
VI	8	—	29.2	0.95	83.9
VI delay	14	1.35	15.6	0.82	72.2

these schedules. An arithmetic progression was used to construct the interval tape used in each schedule (*cf.* Catania and Reynolds, 1968). The VI schedule was arranged so that on the average of once every 60 sec the tape programmer initiated an interval timer (clock) that operated for 3 sec (in the session columns of Table 1 marked *, the timer operated for 6 sec). At the end of the timer operation the next key peck was reinforced. In this and the other conditions, the tape programmer did not operate from the time the tape programmer microswitch was activated until the end of reinforcement.

The unsignalled delay-of-reinforcement condition (referred to henceforth as VI delay) was a tandem VI 60-sec FT 3-sec schedule (or tandem VI 60-sec FT 6-sec in the session columns of Table 1 marked *). The first key peck after activation of the tape programmer microswitch started the interval timer. When the timer completed operation, the reinforcer was presented independently of the key-peck response. No exteroceptive stimulus changes accompanied the operation of the timer.

During the VT schedule, the activation of the tape programmer microswitch initiated the interval timer operation. At completion of the timer operation, reinforcement occurred independently of responding.

Fig. 1. Schematic diagram of the different schedules. Time progresses from left to right. Deflections of the lines from the baseline levels indicate responses or operation of the labelled equipment. "TP" refers to tape programmer.

Birds 24, 84, and 96 were used to examine the role of reinforcement frequency changes in the effects obtained with the experimental subjects. Each was trained on a VI 63-sec schedule before being yoked with one of the experimental subjects (Birds 10, 33, and 61). Sessions for pairs of yoked and experimental subjects were conducted simultaneously in the two chambers. In the conditions where yoked control subjects were included, the delivery of a reinforcer to the experimental subject made reinforcement available to the yoked control subject following its next key peck. Thus, each yoked control subject was always exposed to a VI schedule, with the frequency and distribution of reinforcements determined by the experimental subjects.

Changes in experimental conditions were made only when the behavior of the experimental subjects was stable. Stability was defined by the occurrence of a six-day period in which the mean of the first three days and the mean of the last three days did not differ by more than $\pm 2.5\%$ of the six-day mean. Some conditions were extended beyond the point where the stability criterion was met to assess long-term effects of the schedules. Sessions were conducted daily and each session terminated after delivery of 60 reinforcers.

RESULTS

Response rates were highest during VI, at an intermediate level during the VI delay (tandem) schedule, and lowest during VT. These data are summarized in Table 1. Figure 2 shows stable VI performance and the first and last six days of VI delay and VT during the first exposure to each of these schedules for Birds 10, 33, and 61. The VI delay (tandem) schedule reduced response rates within a few sessions and the rates stabilized at a level below that obtained during VI. The VT schedule further reduced response rates, followed by stabilization of the rates at a level below that obtained during VI delay. Bird 33 was given only six sessions of VT during the condition shown because its response rates fell to near zero after three sessions.

The cumulative records in Figures 3 and 4 illustrate the effects of the different schedules within individual sessions. The VI performance of each subject was characterized by uniform response rates throughout the session.

Fig. 2. Responses per minute during the last six sessions of VI and the first and last six sessions of VI delay and VT for each experimental animal during the first exposure to each of the schedules. The different schedules are separated by the solid lines and the first and last six sessions are separated by dashed lines.

During VT (Figure 3), response rates were low with long periods of no responding. The different subjects exhibited different patterns of responding during the VI delay schedule. In addition, changes in response patterns were sometimes observed across successive exposures to the VI delay schedule. The behavior of Bird 33 (Figure 4), for example, was characterized by a "break-and-run" pattern during the first exposure to the VI delay schedule in which short bursts of several responses followed a long pause in responding. During subsequent exposures to this schedule, this general pattern continued, but relative duration of pauses and length of response bursts changed. Bird 33 was the only subject that

Fig. 3. Sample cumulative records of the performance of Bird 10 during VI, VI delay (third session and stable performance) and VT (stable performance). Deflections of the response pen indicate reinforcement delivery.

substantially increased its response rates between the first and second exposures to the VI delay schedule.

The average obtained delays between the last response before reinforcement and reinforcement are also provided in Table 1 for the experimental birds. During VI, these delays were zero since reinforcement was contiguous with the key peck. During VI delay, the average delay increased and during VT there was a further increase in the average delay.

During the VI delay schedule, frequency of reinforcement (number of reinforcements/total time in session) was lower than that ob-

Fig. 4. Sample cumulative records of the performance of Bird 33 during the last session of the last exposure to the VI schedule and during stable performance at each of the first two exposures to the VI delay schedule. Deflections of the response pen indicate reinforcement delivery.

tained during either the VI or VT schedule (see Table 1). Each yoked control subject, which received equivalent reinforcement following the first key peck after the experimental bird's responding was reinforced, showed unsystematic changes in response rates as a function of these changes in reinforcement frequency. During the third exposure of the experimental animals to the VI delay schedule, two of the three yoked control animals increased their response rates relative to the previous sessions. This may have been the result of unstable behavior, since the yoked birds were changed when the experimental birds exhibited stable performance. For this reason, the experimental birds were subsequently returned to VI and then again changed to the VI delay schedule. During the final VI delay schedule with the experimental birds, the yoked control subjects still showed unsystematic changes in response rates relative to their previous rates, but response rates of each experimental subject decreased as during previous VI delay schedules.

DISCUSSION

The effect of retaining the dependency while allowing contiguity to vary was to reduce responding considerably; however, some responding was maintained for up to 62 sessions during this condition. Introduction of VT schedules, in which the dependency was eliminated while allowing variability in the temporal interval between reinforcement and responding generally further reduced responding. These behavioral changes from VI to VI delay to VT were positively correlated with increases in the interval between the last response before reinforcement and reinforcement delivery.

The role of several variables in controlling this performance must be considered. The fact that the yoked control subjects showed no systematic changes in responding precludes an account of the VI delay schedule effects on responding exclusively in terms of the frequency or distribution of reinforcement. The sequencing of schedules was not random and, as a result, two of the three VT schedule conditions followed the VI delay schedule. Thus, on these occasions, VT was affected after response rates were reduced to low levels. If lower response rates are less likely to maintain close temporal contiguity between responding and reinforcement than are higher rates, it may be that the VT maintained lower rates than VI delay simply as a result of being introduced after a low-rate baseline schedule. This argument seems precluded since at least one bird (Bird 61) showed an equivalent rate in VT regardless of whether the VT followed VI or VI delay. The present conclusions are also somewhat restricted by the use of only one delay value for each subject (Bird 10 was studied under two delay values, but actual obtained delays were determined only during the tandem VI 60-sec FT 6-sec schedules). Additional research with several delay values is necessary to quantify further the relation between response rate and delay values.

The operations studied in this experiment were on a continuum of precision of specification of behavior at the time of reinforcement. While not even response-dependent, "contiguous" reinforcement allows precise specification of the behavior at the time of reinforcement (*cf.* Zeiler, 1968), in relative terms it allows considerable precision. Procedures that de-

crease precision over the specification of the measured response at the time of reinforcement often result in progressively lower rates of that response. Allowing variation in response-reinforcer contiguity while retaining the dependency represents an intermediate level of precision of specification of the temporal relation between the measured response and reinforcement. During the present VI delay schedule, the dependency prevented the interval between responding and reinforcement from exceeding the value of the FT schedule (3 sec, or 6 sec for Bird 10) during VI delay. Shorter average delays between responding and reinforcement were not precluded and were, in fact, obtained. Thus, the dependency in part exerts an indirect effect on behavior through its effects on temporal contiguity. Response-independent reinforcement minimizes the precision of control over the measured response at the time of reinforcement and results in the lowest response rates.

The necessity of temporal contiguity between a response and a reinforcer in controlling behavior has been questioned in recent theoretical accounts of reinforcement (*e.g.*, Baum, 1973; Bloomfield, 1972). As both Baum and Bloomfield note, empirical tests of such a suggestion are difficult to devise. Neither a signalled delay of reinforcement procedure nor an unsignalled delay-of-reinforcement procedure with a DRO schedule in the terminal link (*cf.* Azzi *et al.*, 1964) are unconfounded examples of retaining the dependency while eliminating contiguity. In the former procedure, conditioned reinforcing effects cannot be ruled out; in the latter procedure, reinforcement is dependent on the absence of a specified response. The present procedure and an unpublished experiment by Herrnstein (cited by Baum, 1973, p. 147) are more illustrative of a dependency without a requirement of contiguity between response and reinforcement. In this experiment, procedures that resulted in increased variability in the temporal relation between response and reinforcement led to decreases in responding. This result seems consistent with Baum's suggestion that increased variability in response-reinforcer contiguity with a constant dependency may reduce, but not eliminate, responding. However, neither the present procedure nor the example of Herrnstein's experiment unequivocally

cally eliminate the possibility that the behavior is maintained by occasional adventitious temporal contiguity between responding and food presentation.

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