SIGNAL FUNCTIONS IN DELAYED REINFORCEMENT

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Three experiments were conducted with pigeons to examine the role of the signal in delay-of-reinforcement procedures. In the first, a blackout accompanying a period of nonreinforcement increased key-peck response rates maintained by immediate reinforcement. The effects of dissociating the blackout from the delay interval were examined in the second experiment. In three conditions, blackouts and unsignaled delays were negatively correlated or occurred randomly with respect to one another. A signaled delay and an unsignaled delay that omitted the blackouts were studied in two other conditions. All delay-of-reinforcement conditions generally produced response rates lower than those produced by immediate reinforcement. Signaled delays maintained higher response rates than did any of the various unsignaled-delay conditions, with or without dissociated blackouts. The effects of these latter conditions did not differ systematically from one another. The final experiment showed that response rates varied as a function of the frequency with which a blackout accompanied delay intervals. By eliminating a number of methodological difficulties present in previous delay-of-reinforcement experiments, these results suggest the importance of the signal in maintaining responding during delay-of-reinforcement procedures and, conversely, the importance of the delay interval in decreasing responding.

Key words: signal functions, delay of reinforcement, blackout, variable-interval schedules, key peck, pigeons

Signaled delay-of-reinforcement procedures, whether using blackouts or other stimuli, typically involve simultaneous disruption of response-reinforcer temporal contiguity and introduction of a new stimulus (e.g., Ferster, 1953; Morgan, 1972; Pierce, Hanford, & Zimmerman, 1972). One question about signal functions raised by such procedures is that of the effects of introducing a signal on responding even in the absence of the delay. A second is how the positive correlation between the signal and the delay interval controls responding relative to the independent effects of these two events.

Only a few experiments using signaled delays have attempted to answer the first

question. Ferster (1953) reported that response-dependent and response-independent blackouts of the same duration and frequency as those accompanying the delay interval during signaled delays of reinforcement had no systematic effect on responding when imposed during an immediate-reinforcement variable-interval (VI) schedule. Chung (1965) studied the effect of signaled delays (blackouts) of different durations occurring during one component of a concurrent VI VI schedule. The second component arranged an identical schedule except that the response-produced blackouts accompanied periods of nonreinforcement. Response rates were lower in the signaled-delay component, leading Chung to conclude that blackouts uncorrelated with delays did not affect response rates as much as did signaled delays of reinforcement. Pearce and Hall (1978, Exp. 2) compared the response rates of groups of rats maintained under either a VI schedule or a VI schedule that included response-produced 500-ms light flashes uncorrelated with reinforcement with that maintained by a VI schedule with a 500-ms

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delay of reinforcement signaled by the light flash. Responding was equal in the two former conditions and in each of these conditions it was higher than that during the signaled delay.

Methodological difficulties in these, and most other, studies of signaled delay of reinforcement preclude firm conclusions about signal functions in such procedures. For example, in Ferster's and in Chung's control conditions for the effects of the blackouts, the blackouts were imposed during an immediate-reinforcement condition (VI schedule) and were explicitly unpaired (negatively correlated) with reinforcement. Stimuli accompanying periods of extinction may have a variety of behavioral effects on responding at other times (Reynolds, 1961; Sadowsky, 1973). If VI responding during the blackout control condition is affected by the resulting extinction contingency, comparisons between the effects of this condition and the signaled delay seem questionable. Pearce and Hall (1978, Exp. 2) indicated that in their uncorrelated condition the signal and the food occurred independently of one another. However, their response-produced signals were sufficiently brief (500 ms) that it seems likely that food delivery never occurred in their presence. Neither is it known whether such signals controlled an absence of responding. Even if the uncorrelated condition truly was functionally uncorrelated, the generality of the finding of no difference between the uncorrelated condition and a VI condition still is limited by the brevity of the signal.

The question of the role of the positive correlation between the signal and the delay interval in delay-of-reinforcement effects has not been addressed directly. However, experiments by Azzi, Fix, Keller, and Rocha e Silva (1964) and by Richards (1981) are relevant. Azzi et al., using rats, compared delays of different durations that were signaled (by a blackout) and unsignaled in different phases of the experiment. Each response during the delay interval restarted the interval. Richards, using pigeons, also compared delays of different duration that were unsignaled or signaled by illumination

of a pilot light at the rear of the chamber. Richards' procedure did not include a response-reset requirement. Despite this difference in the reset requirement, both Azzi et al. and Richards found that signaled delays maintained higher response rates than otherwise nominally equivalent unsignaled delays.

Neither Azzi et al. (1964) nor Richards (1981) directly compared signaled- and unsignaled-delay effects with immediate reinforcement effects. Rather, comparisons were more directly made between the two types of delay. Azzi et al. programmed one type of delay during the first half of a session and the other during the second half. Richards used a similar design, but the different types of delays occurred in the first and second half of 48-day blocks of sessions at each delay value. Further, in neither study were there controls for changes in reinforcement frequency between the different delay values or between these delays and the immediate-reinforcement condition (cf. Lattal, *in press*; Weil, 1984).

Two other procedures may be useful in investigating the effects of the correlation between the signal and the delay interval. One is to dissociate the delay interval and the signal. Another is to vary the degree of positive correlation between them. Extant comparisons of signaled and unsignaled delays have compared only those conditions in which the signal is always or never present (Azzi et al., 1964; Richards, 1981). With only these two extreme values (signal always or never present during the delay), conclusions about the functional relation between the positive correlation of signal and delay interval and response rate cannot be drawn. Dissociation of the signal and the delay interval has not been studied in the context of operant delay of reinforcement. However, such a control procedure often is used in studies of respondent conditioning (see Rescorla, 1967).

The present experiments examined these functions of signals as they relate to the interpretation of signaled delay-of-reinforcement effects. Blackouts and delays were

presented in different relations to one another to assess the relative contributions of each to performance. Each configuration of blackout and delay also was preceded and followed by immediate reinforcement to permit direct comparisons of the effects of each configuration to this condition.

GENERAL METHOD

Subjects

Male White Carneaux pigeons were maintained at 80% of free-feeding weights. Some were experimentally naive and others had histories of key pecking on various schedules of positive reinforcement, as noted below.

Apparatus

An operant conditioning chamber (Gerbrands Model 67311) was housed in a sound/light attenuating enclosure (Gerbrands Model 67210). The chamber contained a single response key, operated by a force of 0.14 N, centered on the work panel 25.5 cm from the floor. The key was transilluminated red except during reinforcement and blackout. During all conditions, reinforcement was 4-s access to mixed grain in a hopper located behind a 5-cm square aperture centered on the work panel 8.5 cm from the floor. The aperture was illuminated by two G. E. #1819 lights operated by 28 V during reinforcement. Two similar white 28-V lights, located adjacent to each other in the center of the ceiling, were illuminated continuously except during reinforcement and blackouts. White noise and a ventilating fan masked extraneous sounds. Electromechanical programming and recording equipment was located in an adjacent room.

Procedure

After the naive pigeons were adapted to the chamber, the key-peck response was shaped. Key-peck responding of both experienced and naive pigeons then was stabilized under a VI schedule. During Experiments 2 and 3, the schedule was arranged such that at the end of an average 50-s interval determined by a constant probability dis-

tribution (Catania & Reynolds, 1968), a film programmer stopped and initiated a 20-s interval. The first response after the end of the 20-s interval delivered the reinforcer. During Experiment 1, the schedule was similar except that the 20-s interval was omitted. In Experiments 2 and 3, a second film programmer, containing an average 50-s interval distribution identical to the VI food schedule, operated independently of and not in synchrony with the VI schedule. When an interval on this distribution elapsed, it initiated a 20-s unsignaled period during which reinforcement was unavailable and the VI schedule film programmer was inoperative. These unsignaled intervals of nonreinforcement during the VI schedule will be referred to hereafter as "sham" intervals. During some of the conditions, these intervals were accompanied by blackouts in the chamber, referred to hereafter as "blackout" intervals. The VI schedules were arranged in this manner in an attempt to more closely equate reinforcement frequency between this baseline condition and the various conditions of Experiments 2 and 3 that followed (Lattal, in press; Weil, 1984). The specific procedures of each experiment involved comparisons of VI schedule performance with different combinations of blackout and delay intervals as described below.

EXPERIMENT 1

Periods of nonillumination in an operant chamber (blackouts) unaccompanied by reinforcement often increase response rates when imposed during schedules (e.g., Reynolds, 1961; Sadowsky, 1973). Ferster's (1953) conclusion, based on a qualitative analysis of cumulative records, was that imposing such blackouts during a VI schedule had no systematic effect on responding. The present experiment replicated Ferster's conditions but included a quantitative analysis of the effects of both response-dependent and response-independent blackouts on VI schedule responding.

METHOD

Subjects

Three male White Carneaux pigeons with a history of key-peck responding were used.

Procedure

The sequence of conditions is given in Table 1. The VI baseline schedule described in the general procedure section alternated with two conditions in which blackouts in the chamber were imposed during the VI schedule. In one condition the first response after completion of an average 50-s interval, determined by a second film programmer, produced a 20-s blackout. In the other condition, the 20-s blackout occurred independently of responding. The VI schedule was inoperative during the blackouts (extinction, EXT). Each of these two conditions was preceded and followed (except for Bird 9268) by a return to the VI baseline schedule. The baseline schedules were in effect until responding stabilized. Stability was defined by six consecutive sessions in which the mean of the first and last three days did not differ by more than 3% from the six-day mean. The conditions with blackouts were in effect for either 25 days (Birds 17 and 5533) or for 15 days (Bird 9268). One-hour sessions occurred 5 days a week.

RESULTS AND DISCUSSION

Figure 1 shows that both response-dependent and response-independent blackouts accompanied by extinction periods increased response rates during the VI schedule. The effects of the two types of

blackouts on VI responding were not appreciably different from one another. In only one instance (Bird 9268, during the condition with response-independent blackouts) was the positive behavioral contrast effect questionable. Visual observation of this bird indicated a shift in response topography toward a large proportion of off-key pecks during this condition. Table 1 shows that both blackout conditions decreased reinforcement frequency by approximately the same amount relative to the immediate reinforcement condition. Because blackout occurrence and reinforcement frequency reduction occurred simultaneously, as in Ferster's (1953) experiment, the independent contributions of these two variables cannot be assessed.

These findings are consistent with the substantial literature on positive behavioral contrast (e.g., Reynolds, 1961; Sadowsky, 1973) but not with Ferster's (1953) report. Blackouts accompanying periods of extinction imposed during VI schedules facilitated responding maintained by immediate reinforcement. This can be interpreted in different ways. First, most studies of delay of reinforcement are based on comparisons of signaled-delay effects and a condition in which signals are not present (e.g., Azzi et al., 1964; Morgan, 1972; Pierce et al., 1972; Richards, 1981). If the present condition is an appropriate baseline against which signaled-delay effects are to be compared, these previous reports underestimate the absolute effects of delays. This is the case because the signal accompanying the extinction period elevates response rates relative

Table 1

Sequence of conditions, number of sessions, and mean number of reinforcers per minute (S^R/Min) during the last six sessions of each condition for each subject in Experiment 1. See text for description of each condition.

Condition	Bird 17		Bird 5533		Bird 9268	
	Sessions	S^R/Min	Sessions	S^R/Min	Sessions	S^R/Min
Baseline	20	1.08	14	1.04	20	1.02
Response-dependent blackout	25	0.82	25	0.79	15	.78
Baseline	27	1.00	30	1.02	21	1.13
Response-independent blackout	25	0.80	25	0.82	15	.79
Baseline	13	1.10	19	1.10	—	—

Fig. 1. Responses per minute during the last six VI baseline sessions (B) and during each session in which responding produced blackouts (RDBO) and in which blackouts occurred independently of responding (RIBO) for each subject in Experiment 1. The sequence of conditions for all birds is indicated above the top set of axes.

to the immediate-reinforcement condition without such a signal. Second, the blackout always terminates with reinforcement during a signaled-delay procedure, and this is likely to have very different behavioral effects from a blackout correlated with nonreinforcement. However, if blackouts have similar effects on responding maintained by signaled-delayed reinforcement, then such responding would be due to an interaction of at least three variables: the delay, the signal itself, and the pairing of signal and reinforcement. If, on the other hand, blackouts accompanying extinction and those preceding food delivery do not function similarly, the present procedure of confounding blackout and extinction does not seem a useful way of separating the effects of

the signal as such from its role in preceding food presentations.

EXPERIMENT 2

The first experiment examined the functions of signals when comparisons are made between immediate and delayed reinforcement. The second experiment addressed the role of the positive correlation between the signal and the delay interval during delayed reinforcement. Blackouts were imposed during a delay-of-reinforcement condition rather than during a schedule of immediate reinforcement. Signaled and unsignaled delays were compared with unsignaled-delay procedures that included blackouts that were negatively correlated or uncorrelated with

the delay interval. In addition, unlike Ferster's (1953) experiment or the first experiment above, an attempt was made to equate reinforcement frequency between the immediate- and delayed-reinforcement conditions.

METHOD

Subjects

Four experimentally naive pigeons and one (5533) with a history of reinforced key-peck responding were used.

Procedure

The sequence of conditions is given in Table 2. For four of the birds, the baseline schedule described in the general method section alternated with each of five types of delay conditions in different orders. Bird 5533 was studied under the baseline condition and an unsignaled delay with response-independent blackouts. The baseline condition was then changed for Birds 494 and 5533 by equally lengthening the durations of both the fixed interval preceding reinforcement and the interval arranged by the second film programmer to 75 s (and then to 150 s for Bird 5533). The different delay conditions then alternated with each of these latter baseline schedules.

The delay conditions were as follows:

Signaled delay (S): a chain VI 50-s FT 20-s (or 75-s or 150-s) in which the first response after completion of the VI interval initiated a 20-s (or 75-s or 150-s) delay that was accompanied by a blackout in the chamber. A second film programmer arranged 20-s (or 75-s or 150-s) unsignaled intervals of nonreinforcement. When these sham intervals were in effect, the VI film programmer was stopped. Thus, the delay interval and the sham interval were mutually exclusive.

Unsignaled delay ($\bar{S}$): identical to the signaled delay except that the blackout preceding reinforcement was omitted. Responding during the delay interval had no effect on food delivery.

Unsignaled delay with response-dependent blackouts ($\bar{S}$; RDBO): identical to the unsignaled

delay condition except that responding produced 20-s blackouts according to a VI 50-s schedule. During this condition the blackouts replaced the sham intervals. Blackouts and unsignaled-delay intervals were mutually exclusive. During the blackouts, the VI film programmer was inoperative.

Unsignaled delay with response-independent blackouts ($\bar{S}$; RIBO): identical to the unsignaled delay with response-dependent blackouts, except that blackouts occurred as soon as they became available and were independent of the bird's responding.

Random blackouts ($\bar{S}$; RBO): identical to the unsignaled delay with response-independent blackouts except that it was possible for blackouts and unsignaled delays to overlap with one another in time. Thus, for example, if an unsignaled delay interval was in effect, a blackout could be initiated. Food delivery then would occur during the blackout upon completion of the delay interval.

Each delay condition was in effect for a minimum of 13 sessions and until either a stability criterion was met or until response rates fell below 2 responses per minute for six consecutive sessions. Baseline-schedule conditions were in effect for at least 13 days and until the stability criterion was met. The stability criterion for all conditions required that mean response rates, excluding the sham interval and the 20-s (or 75-s or 150-s) interval preceding reinforcement, during the last six sessions of the condition not differ by more than 3% from the means of the first and last three sessions during that six-session period. Sessions were conducted 5 days a week and lasted until either 40 (or 20, in the case of the 75- and 150-s delay intervals) reinforcers occurred.

RESULTS AND DISCUSSION

Table 2 provides mean response rates during the VI component (excluding responding during the delay and blackout/sham intervals), local response rates during the blackout/sham interval and during the 20 s preceding reinforcement (delay interval), and reinforcement frequency for each condition. Figure 2 summarizes the mean VI

Table 2

Sequence of conditions; number of sessions; mean responses per minute during the VI component, the blackout (BO)/sham interval, and the delay interval; and mean number of reinforcers per minute (S^R/Min) for each subject in Experiment 2. The response-rate and reinforcement-frequency data are means of the last six sessions for each condition. The abbreviations for the conditions are as follows: S = signaled delay; $\bar{S}$ = unsignaled delay; $\bar{S}$; RDBO = unsignaled delay with response-dependent blackouts; $\bar{S}$; RIBO = unsignaled delay with response-independent blackouts; $\bar{S}$; RBO = unsignaled delay with random blackouts. The delay duration and the duration of the blackout/sham interval was 20 s except for the data for Bird 494 below the dashed line, for which the duration of both of these intervals was 75 s, and for Bird 5533, for which in the first block it was 20 s, in the second block it was 75 s, and in the third block it was 150 s.

Condition	Sessions	Responses per Minute			S^R Min
		VI	BO/Sham Interval	Delay	
<i>Bird 79</i>					
Baseline	21	59.4	67.2	71.1	.64
S	20	32.9	33.7	3.9	.65
Baseline	20	53.1	57.3	62.3	.56
S; RDBO	20	9.9	3.5	14.6	.56
Baseline	16	40.1	48.2	57.0	.65
S; RIBO	16	5.0	0.1	9.6	.54
Baseline	13	46.5	45.9	54.1	.65
S; RBO	13	12.1	3.4	18.2	.72
Baseline	20	46.5	52.2	56.0	.65
S	13	5.9	7.3	11.2	.56
<i>Bird 493</i>					
Baseline	20	46.9	47.9	50.2	.65
S; RDBO	20	1.6	3.1	6.5	.36
Baseline	13	28.0	31.4	36.2	.64
S; RIBO	20	0.8	0	5.2	.44
Baseline	18	30.9	33.3	36.0	.65
S	18	49.2	49.7	3.9	.65
Baseline	17	40.1	42.4	51.2	.64
S	29	2.0	3.9	7.0	.52
Baseline	35	29.8	29.1	36.1	.64
S; RBO	40	3.3	3.2	7.1	.73
<i>Bird 494</i>					
Baseline (20 s)	21	54.7	60.7	66.5	.64
S; RIBO	22	22.7	0.3	65.2	.58
Baseline	13	48.7	54.9	60.5	.64
S	22	30.5	31.2	3.1	.65
Baseline	21	50.1	52.1	59.6	.64
S; RDBO	25	39.8	3.0	73.5	.58
Baseline	30	52.8	54.7	63.1	.63
S	20	29.0	37.9	56.7	.63
Baseline	24	55.4	70.0	71.8	.62
S; RBO	22	3.5	3.6	11.6	.55
Baseline	15	48.0	50.0	62.5	.62
<hr/>					
Baseline (75 s)	30	38.1	44.8	56.9	.32
S; RIBO	24	0.4	0	5.8	.17
Baseline	14	33.1	38.0	43.3	.29
S; RDBO	30	1.8	1.4	4.4	.17
Baseline	20	38.4	47.7	55.2	.30
S; RBO	35	5.8	1.3	10.8	.31
Baseline	25	48.4	60.1	66.4	.29
S	67	4.8	10.7	14.3	.29
Baseline	15	41.6	48.8	54.2	.32
S	39	32.1	37.0	1.4	.31
Baseline	14	35.9	49.9	55.0	.31

Table 2—Continued)

Condition	Sessions	Responses per Minute			S ^a Min
		VI	BO/Sham Interval	Delay	
<i>Bird 2682</i>					
Baseline	32	30.3	34.8	37.2	.62
S; RDBO	28	6.8	3.0	24.4	.42
Baseline	23	23.3	27.6	30.0	.60
S; RIBO	30	2.9	0	7.7	.42
Baseline	33	28.0	33.6	35.9	.60
S; RBO	25	1.5	0	10.4	.31
Baseline	13	28.5	31.7	31.9	.64
S	22	15.5	19.5	2.4	.61
Baseline	15	31.6	31.5	37.6	.63
S	35	2.5	3.6	6.8	.55
<i>Bird 5533</i>					
Baseline (20 s)	25	44.1	51.5	49.3	.63
S; RIBO	46	60.0	0.7	74.9	.65
Baseline	14	72.0	75.5	87.6	.65
Baseline (75 s)	18	40.0	52.5	57.8	.29
S; RIBO	25	9.3	0	46.8	.33
Baseline	18	41.8	52.9	61.1	.29
Baseline (150 s)	63	33.3	42.5	52.1	.17
S; RIBO	21	3.9	0	21.8	.16
Baseline	20	37.4	58.8	66.9	.17

component response rates during the last six sessions of each delay condition expressed as a percentage of the mean VI component response rates during the last six baseline sessions preceding the indicated manipulations. Response rates during VI for Birds 79, 493, and 2682 were highest on the signaled-delay condition. The rates of Bird 493 on the signaled-delay condition substantially exceeded those on the immediate-reinforcement condition. For these three birds, rates on the unsignaled-delay conditions with either response-dependent or response-independent blackouts did not differ systematically from each other or from rates on the unsignaled-delay and random-delay conditions. With the 20-s intervals, the response rates of Bird 494 did not conform to those of the other birds. Response rates generally were higher during all of the delay conditions for this subject than for the others. The response rates expressed as a percentage of baseline for this subject were highest during the unsignaled delay with the response-dependent blackouts and lowest during the random-blackout condition. A systematic replication of the experiment with this subject using a longer delay value (75-s) pro-

duced the data shown below the dotted line in Table 2 and in Figure 2. With the longer delay and blackout conditions, the data conformed to those for the other three birds with the 20-s delay. This effect also was confirmed with Bird 5533. The original intent was to expose Bird 5533 to the same sequence as the others. However, during the first experimental condition (S; RIBO), this bird showed a substantial increase in its responding relative to the immediate baseline condition. Thus, the unsignaled delay with negatively correlated, response-independent blackouts was replicated with different delay/blackout durations. Longer durations resulted in lower absolute and relative rates, as shown in Figure 2 and Table 2.

The attempt to equate reinforcement frequency across baseline and delay conditions was only partially successful. Except for the signaled-delay conditions, response rates during the delay conditions often were sufficiently low that decreases in reinforcement frequency often resulted. However, these relatively small decreases in reinforcement frequency cannot independently account for the substantial decreases in response rates.

Fig. 2. Mean response rates during the last six sessions of each of the different delay procedures expressed as a percentage of the mean of the response rates in the last six sessions of the immediately preceding nondelay baseline condition for each subject in Experiment 2. From left to right for all subjects except Bird 5533, the conditions indicated below the y axis are signaled delay (S), random blackout ($\bar{S}$; R), unsignaled delay with response-independent blackouts ($\bar{S}$; RI), unsignaled delay with response-dependent blackouts ($\bar{S}$; RD), and unsignaled delay ($\bar{S}$). For Bird 5533, the condition was always unsignaled delay with response-independent blackouts. With the exceptions of Birds 494 and 5533, all conditions utilized 20-s delay and blackout/sham intervals. The data for Bird 494 shown in the top center graph also were from conditions utilizing the 20-s intervals. The data for Bird 494 in the top right graph were from conditions utilizing 75-s delay and blackout/sham intervals. The data for Bird 5533 (lower right graph) were from conditions utilizing the duration of delay and blackout/sham intervals shown in parentheses (in seconds) above each bar. Values below and above 100 indicate, respectively, decreases and increases in response rates in the condition shown relative to the immediately preceding baseline condition.

Conditions in which the signal was positively correlated with the delay consistently maintained higher rates than the other configurations of signal and delay interval. Only with Bird 494 at the 20-s delay did signaled delays and unsignaled delays with or without negatively correlated blackouts maintain nearly equal responding. Increasing the delay to 75 s with Bird 494 produced greater reductions by the unsignaled delays (cf. Richards, 1981). Given the large

individual differences in the effects of delay of reinforcement, the equal responding with signaled and unsignaled delays at some durations is not surprising.

In several instances (Bird 494, 75-s delay; Birds 79 and 493), the random-control procedure maintained somewhat higher rates than the unsignaled delays with or without negatively correlated blackouts. The random control did not rule out an occasional pairing of blackouts and delays. In light of

the other findings of this experiment, rates would be expected to be higher to the extent that such pairings occur.

More generally, these results suggest that blackouts uncorrelated or negatively correlated with delays of reinforcement have no systematic effect on responding that is any different from the effects of the unsignaled delay alone. Comparisons of response rates in the unsignaled-delay condition and those during the negatively correlated blackout conditions ($\bar{S}$, RDBO; $\bar{S}$, RIBO) did not suggest a behavioral-contrast effect like that found in Experiment 1 when these blackouts were imposed during an immediate-reinforcement condition. However, in Experiment 1 reinforcement frequency decreased an average of 24% from the immediate-reinforcement condition to the conditions with blackouts. By contrast, in Experiment 2 the average reinforcement frequency was 11% higher in the conditions with blackouts (calculated using the conditions with 20-s blackouts) than in the unsignaled-delay condition. Thus, this absence of contrast may relate to the better control of reinforcement frequency in Experiment 2. The differences in response rates maintained by the schedules may also be a factor in the differing effects in the two experiments. Blackouts may induce rate-enhancing, behavioral-contrast effects during delay-of-reinforcement conditions but these contrast effects may be masked by the rate-decreasing effects of the delay itself. Because of the possibility of such schedule interactions, blackouts explicitly unpaired with reinforcement do not seem a satisfactory control procedure for isolating signal effects in delay of reinforcement.

EXPERIMENT 3

This experiment further examined the effects of a positive correlation between signal and delay on responding by systematically varying the frequency with which a signal accompanied the delay interval. As noted in the introduction, previous comparisons of the effects of such a correlation on response maintenance have been limited to delays

that are always or never signaled (Azzi et al., 1964; Richards, 1981).

METHOD

Subjects

Five experimentally naive White Carneaux pigeons were maintained at 80% of their free-feeding weights.

Procedure

The key-peck response was shaped and then stabilized under a VI schedule identical to that used as the baseline schedule in Experiment 2. The durations of both the sham intervals and the delay intervals were 20 s. The birds subsequently were exposed to the conditions in Table 3. The baseline-schedule condition, arranging immediate reinforcement, alternated with delay of reinforcement conditions in which 0%, 33%, 66%, or 100% of the reinforcers were preceded by a 20-s signaled delay and the remainder were preceded by a 20-s unsignaled delay. The sequence of signaled and unsignaled delays preceding reinforcement was determined by a semirandom distribution, with the restriction that no more than three of either type of delay could occur successively. The same stability criterion employed in Experiment 1 was used here, except that the minimum number of sessions per delay condition was 22. Sessions were conducted 5 days a week and lasted until 40 reinforcers were delivered. Birds 144, 4077, and 5533 were studied first; the results from Bird 4077 indicated that replication was in order. Therefore, Birds 887 and 1373 were studied several months after the first three birds had completed the experiment.

RESULTS AND DISCUSSION

Table 3 provides mean response rates during the VI component, during the sham/blackout interval, and during the 20 s preceding reinforcement; also given is the reinforcement frequency for each condition. These data were compiled from the last 6 days at each condition. Figure 3 shows response rates during the VI component

Table 3

Sequence of conditions; number of sessions; mean responses per minute during the VI component, the blackout (BO)/sham interval, and the delay interval; and mean number of reinforcers per minute (S^R/Min) for each subject in Experiment 3. The response-rate and reinforcement-frequency data are means of the last six sessions for each condition. The percentage is that of the total reinforcers preceded by signaled delay intervals. The remainder of the reinforcers under each condition were preceded by unsignaled delay intervals.

Condition	Sessions	Responses per Minute			S ² Min
		VI	BO/Sham Interval	Delay	
Bird 144					
Baseline	37	57.7	62.3	67.7	.64
100%	28	48.7	49.3	3.4	.64
Baseline	18	52.0	55.5	60.6	.65
0%	39	3.9	8.5	13.8	.45
Baseline	24	43.8	45.6	48.8	.64
33%	30	9.1	9.3	10.9	.60
Baseline	14	37.2	42.6	45.5	.63
66%	28	14.3	16.1	9.3	.59
Baseline	12	41.9	46.9	49.4	.63
Bird 887					
Baseline	49	59.4	70.0	68.0	.64
33%	57	4.9	7.2	7.2	.55
Baseline	33	80.8	86.5	97.6	.62
66%	26	21.7	24.6	13.2	.63
Baseline	25	74.2	80.3	84.3	.64
0%	91	.4	0.8	3.1	.34
Baseline	16	70.6	79.3	95.1	.68
100%	22	46.2	45.5	3.7	.64
Baseline	13	76.9	93.9	91.5	.66
Bird 1373					
Baseline	27	35.8	42.2	41.9	.62
66%	23	17.3	20.0	10.3	.60
Baseline	18	35.3	36.0	40.8	.64
33%	23	5.2	6.5	7.2	.60
Baseline	16	40.6	42.5	49.5	.64
100%	24	27.5	29.3	3.1	.62
Baseline	13	40.6	42.9	46.8	.62
0%	34	5.9	8.1	7.1	.49
Baseline	15	43.4	49.3	52.3	.66
Bird 4077					
Baseline	34	56.3	59.8	69.8	.64
0%	46	2.2	3.6	7.1	.52
Baseline	37	76.2	71.2	90.4	.65
100%	25	60.2	61.0	3.0	.65
Baseline	69	86.5	104.9	109.5	.63
66%	30	75.7	77.3	32.5	.62
Baseline	22	80.0	91.6	97.7	.63
33%	25	86.4	97.3	73.0	.64
Baseline	14	81.2	90.2	97.7	.64
100%	31	67.1	71.4	2.7	.61
Baseline	48	90.8	94.1	117.1	.64
Bird 5533					
Baseline	26	39.3	41.7	47.6	.64
100%	24	26.3	27.7	3.0	.64
Baseline	14	46.3	46.2	55.7	.64
0%	29	0.7	1.5	5.4	.40
Baseline	41	59.8	60.0	71.7	.64
66%	29	22.2	24.0	11.9	.62
Baseline	17	47.6	53.0	59.0	.63
33%	39	5.4	6.7	7.3	.56
Baseline	14	42.2	48.1	54.5	.62

Fig. 3. Mean response rates during the last six sessions of each condition shown expressed as a percentage of the mean response rates in the last six sessions of the immediately preceding nondelay baseline condition for each subject during each of the different signaled-delay proportions in Experiment 3. The unconnected data point for Bird 4077 (100% signaled-delay condition) is a replication of that condition (see Table 3). Values below and above 100 indicate, respectively, decreases and increases in response rates in the conditions shown relative to the immediately preceding baseline condition.

of each schedule expressed as percentages of VI component rates during the preceding baseline condition, as functions of the percentage of delays that were signaled. Delay of reinforcement generally reduced response rates relative to those maintained by immediate reinforcement. With the exception of Bird 4077, response rates increased with the number of delays preceded by a signal.

Bird 4077's rates were lowest during the unsignaled-delay and highest during the 33% signaled-delay condition. This latter condition was higher than the immediate-reinforcement baseline condition. The 66% and 100% signaled-delay conditions produced intermediate rates, with the latter condition resulting in lower rates than the former on both occasions when it was in effect.

Bird 4077 responded during the 33% and 66% signaled-delay conditions as might be expected if the unsignaled delayed reinforcers were instead immediate reinforcers. That is, if 33% of the reinforcers followed signaled delays and the remainder were delivered immediately after the required key peck, response rates would be higher than the signaled-delay condition (in which all reinforcers would be delayed). Similarly, a condition in which 66% of the reinforcers followed signaled delays and the others were delivered immediately would be expected to result in response rates lower than the condition wherein 33% followed signaled delays and the others were immediate. Thus, Bird 4077's performance could reflect responding to the unsignaled delayed reinforcers as if they were immediate reinforcers.

Utilizing previously omitted control procedures, this experiment confirms the central role of the juxtaposition of the signal and the delay interval in response maintenance during delay of reinforcement. The immediate reinforcement baselines in this experiment, and in Experiment 2, were constructed to equate reinforcement frequency and distribution between that condition and the delay conditions. Controls in the baseline condition for the blackout introduction during the delay interval were not included here because at the onset of these experiments, the proper controls were not known. Nonetheless, the comparison of the effects of the different combinations of signals and delays to each other seems valid, provided the reasonable assumption of a constant effect of signal introduction across delay manipulations.

GENERAL DISCUSSION

The present data suggest a number of signal functions in delay procedures and raise several questions about the nature of reinforcement delay. The issue of appropriate controls in demonstrating delay effects, the roles of signaled and unsignaled delays in the analysis of contiguity effects, and emerging theoretical issues in delay of reinforcement will each be addressed in this discussion.

Several relations are important in assessing the effects of signals in delay-of-reinforcement procedures. One is the positive correlation between the signal and the delay interval followed by food delivery. A second is the effect of the delay procedure relative to that of immediate reinforcement. Another is the effects of different parameters of the delay procedure relative to each other and to immediate reinforcement.

In evaluating the control of responding by the positive correlation of the signal and the delay interval followed by food delivery, it is necessary to examine the effects of these two events independently of one another. The signal may be negatively correlated, uncorrelated, or partially positively correlated with the delay interval. In both Experiments 2 and 3 the signaled delay procedure ensured that each reinforcer that was effected by a response was preceded by a signal. This procedure maintained higher response rates than were produced by procedures with signals that were negatively correlated, uncorrelated, or partially positively correlated with the delay interval followed by food delivery. The absence of systematic differences in the effects of the three control procedures combining unsignaled delays and blackouts in Experiment 2 suggests that they might be equally useful as control conditions. Even though the two procedures involving a signaled EXT period ($\bar{S}$, RIBO; $\bar{S}$, RDBO) did not differ from the random-control procedure, it cannot yet be concluded that such EXT periods are without effect on responding in the nonblackout periods. As noted in the discussion of Experiment 2, this

absence of effect could be due to at least two variables, and neither has been examined experimentally. The random-control procedure therefore seems the better choice as a control procedure in assessing the role of the positive correlation between the delay interval and the signal in signaled-delay effects.

The second comparison of interest is between immediate and delayed reinforcement conditions. First, variables related to frequency and distribution of reinforcers must be held constant between these conditions if valid conclusions about the effects of delay are to be made (Lattal, in press). Second, the effects of intruding a novel stimulus must be considered. The inclusion of the signal during the baseline immediate-reinforcement condition as well as during the signaled-delay condition is one way of controlling for this. In such a case it would be necessary to impose a signal during the immediate-reinforcement condition (cf. Ferster, 1953) rather than during an unsignaled-delay condition as in the comparison discussed in the preceding paragraph. The data in Experiment 1 suggest that procedures in which signals accompany periods of nonreinforcement enhance nonsignal-period response rates and therefore make them questionable as control procedures. An alternative worthy of further investigation is a random-control condition similar to that used in Experiment 2, but imposed on an immediate-reinforcement condition (cf. Pearce & Hall, 1978).

In generating delay-of-reinforcement gradients and in other parametric study of delay of reinforcement, it is useful to precede exposure to delayed reinforcement by an exposure to immediate reinforcement. Without such a design, the rates of responding in each subsequent delay condition may be affected by those in the preceding delay baseline, as may have happened in the experiments of Azzi et al. (1964) and Richards (1981). Appropriate controls for signal introduction also are needed. The delay-of-reinforcement gradient also is potentially confounded by the different reinforcement frequencies concomitant with each delay value (Weil, 1984). One possible solution to

this difficulty is to construct a relative gradient in which the effect of each delay value is compared to an immediate reinforcement baseline that is equivalent in reinforcement frequency and distribution (Sizemore & Lattal, 1978) and in which appropriate controls for signal effects have been included.

The functional relation of interest in experiments on delay of reinforcement is the one between responding and variations in response-reinforcer temporal contiguity generated by the delay procedure. One way of varying this contiguity is to impose a signal during the delay interval. Blackouts presumably were used in early investigations to ensure that operant responding would not occur in the delay (e.g., Ferster, 1953, but cf. Skinner, 1938, p. 138). In subsequent experiments, a variety of other stimuli controlling a variety of other response in the delay interval were investigated (e.g., Pierce et al., 1972). As has been noted many times, such signaled-delay procedures are chain schedules (e.g., Kelleher & Gollub, 1962). Whatever effects they produce are related both to changes in temporal contiguity between the reinforced response and reinforcer presentation and to the immediate response-dependent presentation of a stimulus positively correlated with the reinforcer. Response rates in the unsignaled-delay interval consistently were higher than those in the signaled-delay interval for all subjects in Experiments 2 and 3. Responding that did occur during the signaled delay typically occurred immediately after signal onset as "carry-over" bursts of responses following the one that initiated the signal onset. By contrast, responding in the unsignaled delay was distributed evenly throughout the delay interval. As a result, the average obtained delay between the "reinforced" response and reinforcement was shorter in the unsignaled than in the signaled-delay conditions. Despite these differences in temporal contiguity disruption, the signaled-delay condition maintained higher rates than the (nominally) equivalent unsignaled-delay condition. This suggests that close contiguity of a response with a stimulus positively corre-

lated with the reinforcer is more effective in maintaining responding than is disrupted contiguity between the response and the reinforcer itself.

The confounding of these two processes makes it more difficult to interpret the results of chain-schedule procedures in terms of delay-of-reinforcement effects—that is, changes in temporal contiguity. Eliminating the signal entirely by using an unsignaled delay, or tandem schedule, eliminates both this confusion and the control problems related to the signal discussed above. The relative merits of unsignaled delays have been discussed by others as well (Catania & Keller, 1981; Lattal, *in press*; Sizemore & Lattal, 1978; Williams, 1976).

The analysis of reinforcement delay incorporates its effects on response acquisition and extinction as well as on the maintenance of responding under schedules of reinforcement. As with other behavioral variables, similar effects have been found using the methods of the experimental analysis of behavior and using traditional research designs (e.g., Renner, 1964; Tarpay & Sawabini, 1974). The focus of these latter designs, however, has been primarily on the effects of reinforcement delay on acquisition and extinction, whereas the former has been on response maintenance. Despite frequent similarities in research findings, the focus of theoretical questions in these two research traditions often differs. Tarpay and Sawabini (1974), in their review of many discrete-trial experiments, suggested that "the resolution of most, if not all, issues regarding delay of reward may depend on specifying the mechanism by which cues facilitate delayed-reward performance" (p. 984). Many free-operant experiments, including the present ones, also address this question. Signaled delay-of-reinforcement procedures, or chain schedules, raise interesting problems about behavioral control and certainly are worthy of continued analysis in their own right. The present experiments examined some of these problems and suggested possible solutions. However, the emerging focus of behavior-analytic studies of delay of reinforcement is

the way such reinforcement delays and the response-reinforcer relations that produce them contribute to response maintenance (e.g., Baum, 1973; Catania & Keller, 1981; Sizemore & Lattal, 1977; Williams, 1976). Because of the varied and complicated functions of signals in delay-of-reinforcement procedures, such signaled delays seem less well suited to contribute to this emerging focus that do unsignalled delay-of-reinforcement and related procedures that circumvent these functions.

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