BRIEFLY DELAYED REINFORCEMENT: AN INTERRESPONSE TIME ANALYSIS

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Key-peck responding of pigeons was compared under VI or DRL schedules arranging immediate reinforcement and briefly (.5 sec) delayed reinforcement. Delays were either signaled by a blackout in the chamber, unsignaled, or unsignaled with an additional requirement that responding not occur during the .5 sec interval immediately preceding reinforcement (response delay). Relative to the immediate reinforcement condition, response rates increased during the unsignaled delay, decreased during the signaled delay, and were inconsistent during the response delay condition. An analysis of interresponse times (IRTs) under the different conditions revealed a substantial increase in the frequency of short (0 to .5 sec) IRTs during the unsignaled condition and generally during the response delay conditions compared to that during the immediate reinforcement baseline. Signaled delays decreased the frequency of short (0 to .5 sec) IRTs relative to the immediate reinforcement condition. The results suggest that brief unsignaled delays and, in many instances, response delays increase the frequency of short IRTs by eliminating constraints on responding.

Key words: signaled delay, unsignaled delay, response delay, DRL, VI, interresponse time, pigeons

Rate of responding during reinforcement schedules generally is an inverse function of the interval between the last response and reinforcement. This relation describes the effects of both signaled and unsignaled delays (Azzi, Fix, Keller, & Rocha e Silva, 1964; Ferster, 1953; Richards, 1981; Sizemore & Lattal, 1978) and delay procedures that do and do not require pausing during the delay interval (Azzi et al., 1964; Gonzalez & Newlin, 1976; Pierce, Hanford, & Zimmerman, 1972). Inherent in each of these delay of reinforcement procedures are variables other than changes in response-reinforcer contiguity that contribute to the delay of reinforcement gradient. For example, blackouts or other stimuli during the delay usually ensure that response-reinforcer contiguity is disrupted but not without intruding a stimulus paired with reinforcement. A differential-reinforcement-of-other-behavior (DRO) contingency during an

unsignaled delay interval (hereafter labeled "response delay") eliminates the problem of an intruding stimulus, but resulting decreases in reinforcement frequency caused by continued responding during the delay interval may contribute to response rate reduction. An unsignaled delay procedure without a pause requirement during the delay eliminates problems associated with signals and responding during the delay. One difficulty with this procedure is that, because responding during the delay is irrelevant to reinforcement, actual delays between the last response and reinforcement typically are shorter than the nominal delay. Thus, gradients based on such unsignaled delay procedures can only be established post hoc, once the obtained delays are known (although there is a close relative relation between nominal and obtained delay values—cf. Sizemore & Lattal, 1978). Unsignaled delays of this latter type potentially contribute another variable to delay of reinforcement effects. This variable, removal of constraints on responding, is the focus of the present experiment. To isolate it we first must consider the effects of brief delays of reinforcement.

Briefly delayed reinforcement that is unsignaled often increases response rates relative to those maintained by immediate reinforce-

ment, a potential exception to the previously described relation between rate and delay duration. Sizemore and Lattal (1978) found increases of as much as 50 percent with .5- to 1-sec nominal delays imposed during a variable-interval (VI) schedule with pigeons as subjects. Nominal delays of .5 sec increased mean response rates on six of six occasions and nominal delays of 1 sec increased mean response rates on two of six occasions. Response rates during the other 1-sec delays decreased on two occasions and were unchanged from the immediate reinforcement condition on the other two occasions. Ziegler and Lattal (Note 2) found increases in response rates of pigeons each time .5-sec unsignaled delays were imposed during a differential-reinforcement-of-low-rate schedule (DRL). Richards (1981) replicated these findings: response rates increased with .5- and 1-sec nominal delays with two or three of four pigeons during both VI and DRL schedules. On the other occasions, response rates either decreased or were unchanged from the immediate reinforcement condition. Mandell & Nevin (Note 1) failed to obtain rate increases with a 1-sec unsignaled delay when the delay occurred in one component of a multiple schedule. Other experiments (Richards, 1981; Sizemore and Lattal, 1978) also indicate that a 1-sec delay is less likely to yield rate increases than briefer nominal delays. In addition, since the delay condition was one component of a complex multiple schedule, it is difficult to compare Mandell and Nevin's results directly to those of the above studies where single schedules were employed.

An account of the facilitation of responding by briefly delayed reinforcement is depicted in Figure 1. This figure shows a hypothetical response distribution of pigeons' key pecking superimposed on both a no-delay condition where a response produces immediate reinforcement and a brief-delay condition (.5 sec) where the response that produces the reinforcer and its delivery are not temporally contiguous. The response marked with dots above them represent hypothetical responses that are explained below. Three types of delays are depicted. During the delay with a blackout, the reinforced response initiates the delay and terminates illumination of the chamber. The unsignaled delay (S̄) is identical to the blackout delay, except there is no stimulus change associated with the onset of the delay interval. With both of these delays, responding during the delay is irrelevant to reinforcer delivery at the end of the delay. The response delay (DRO) is identical to the unsignaled delay except that the DRO contingency ensures that a pause of the duration of the delay occurs between the last response and the reinforcer. The response distribution is typical of pigeons under both VI (Blough & Blough, 1968) and DRL schedules. Bursts of several responses separated by short interresponse times (IRTs) are interspersed among responses separated by longer interresponse times. If the reinforcer or the blackout did not occur, the response that produced it would be followed closely in time by the three subsequent responses with the dots above them. If either occurred, an intruding stimulus (food or blackout) would disrupt what would otherwise be a high local rate as indicated by the four-response burst. With the unsignaled delay and the response delay procedures, the first response of the burst ini-
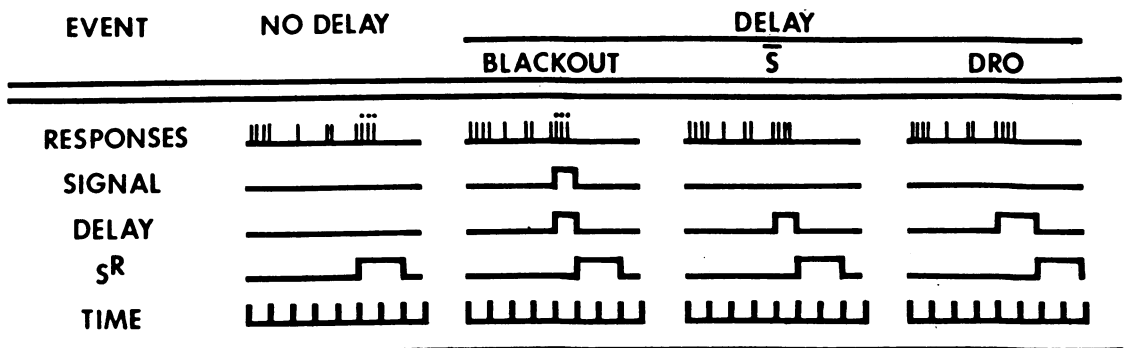

EVENT	NO DELAY	DELAY		
		BLACKOUT	S̄	DRO
RESPONSES				
SIGNAL				
DELAY				
S^R				
TIME				

Fig. 1. Schematic depicting immediate reinforcement and three types of delayed reinforcement procedures: signaled delay (S), unsignaled delay (S̄), and response delay (DRO). Each interval marked on the time scale is .5 sec. S^R indicates food delivery.

tiates the delay. During the unsignaled delay, the remaining three responses occur since there is no stimulus change to disrupt the burst and responding coterminates approximately with food presentation. Similarly, the three remaining responses occur during the response delay procedure. However, because of the pause requirement, reinforcement occurs only after a period of non-responding, defined by the delay duration, following the last response of the burst.

From this analysis it follows that overall response rate increases during unsignaled briefly delayed reinforcement might be due to an increase in local response rates, i.e., an increase in the frequency of short IRTs (bursts of responses) originating from the removal of constraints on their occurrence. Interresponse time distributions can provide evidence of such sequences of short IRTs because characteristic key peck performance of pigeons during VI schedules is such that short IRTs are more likely to be preceded by short, rather than long, IRTs (Blough & Blough, 1968). A predominance of short IRTs in a distribution therefore would suggest the occurrence of bursts of responses. Briefly delayed reinforcement that is signaled or unsignaled should produce different IRT distributions. High local response rates, characterized by more frequent short IRTs, should be more likely with unsignaled delays than with either immediate reinforcement or brief delays accompanied by a blackout. This experiment compared the IRT distributions generated by these different procedures for briefly delaying reinforcement of key pecking during VI and DRL schedules. In addition, a response delay procedure was studied because of its shared features with each of the other two delay conditions. Like the signaled delay with a blackout it ensures that responding is separated from reinforcement by the duration of the delay and like the unsignaled delay it allows the response that initiates the delay to be followed quickly by other responses without interruption prior to food delivery.

METHOD

Subjects

Four white Carneaux pigeons were maintained at 80% of free-feeding weights. Three had experience with various schedules of posi-

tive reinforcement and one (Bird 53) was experimentally naive.

Apparatus

An operant conditioning chamber with a work area 30 by 32 by 39.5 cm was used. The response key was located on the center of the work panel 22 cm from the floor of the chamber. It was transilluminated red by a 28-V ac bulb at all times except during reinforcement. A minimal force of approximately .14 N was required to operate the key. General illumination of the chamber was provided by a white 7-W 110-V ac bulb. Reinforcement was 3-sec access to mixed pigeon grain in a standard food magazine, the opening to which was on the center of the work panel, 8.5 cm from the floor. The opening was illuminated by a white 7-W 110-V ac bulb when the magazine was operated. White noise was presented continuously in the chamber. Supporting relay circuitry and recording equipment were located in an adjacent room.

Procedure

The naive subject was trained to eat from the food hopper and then hand-shaped to peck the response key. For Birds 51, 53, and 69, the schedule was changed over several sessions to VI-60.5 sec. The VI schedule was arranged such that at the end of an average 60-sec interval determined by a constant-probability distribution (Fleshler & Hoffman, 1962) a .5-sec interval was initiated. The first response after the end of the .5-sec interval delivered the reinforcer. This schedule was used to equate reinforcement frequency between the immediate and delayed reinforcement conditions under VI. For Bird 11, the schedule was changed to DRL 20-sec. It was not possible to equate reinforcement frequency between immediate and delayed reinforcement conditions when DRL was in effect since reinforcement frequency was determined by the subject's distribution of responses.

The birds then were exposed successively to the conditions shown in Table 1. Session duration was always 60 min and sessions were conducted five days a week. Changes in conditions occurred only when key pecking was stable. The stability criterion required a minimum of twenty sessions at each condition and, in addition, the mean of the response rates during the last six sessions of the condition could not

Table 1

Sequence of conditions and numbers of sessions at each condition (S = .5-sec signaled delay; S̄ = .5-sec unsignaled delay; D = .5-sec response delay (DRO)); number of reinforcers per session (SR); mean overall rate (responses per minute); and mean local rates (responses per minute) immediately preceding reinforcement (see text for detailed explanation). Each of these latter three measures is a mean of the last six sessions at that condition. A blank space in the delay column indicates no delay in effect. The mean nominal interreinforcement interval for the VI schedules was 60 sec; each DRL schedule required a 20-sec pause before a response could be reinforced (DRL 20-sec).

Pigeon											
		11						51			
Schedule	Delay	Sessions	SR	Overall Rate	Local Rate	Schedule	Delay	Sessions	SR	Overall Rate	Local Rate
DRL		43	5.2	14.0	0	VI		51	55.5	27.7	31.2
DRL	S	20	4.3	13.8	10.5	VI	S̄	21	56.8	33.6	44.8
DRL		39	2.1	16.8	0	VI		35	56.1	32.3	36.2
DRL	S̄	35	3.0	21.9	212.4	VI	S	41	55.6	27.3	34.9
DRL		24	5.0	13.1	0	VI		21	55.8	26.1	35.4
VI		26	56.3	23.8	25.9	DRL		26	12.6	11.3	0
VI	S̄	32	56.2	27.0	81.2	DRL	S̄	26	7.0	22.2	110.3
VI		57	56.5	21.1	32.2	DRL		51	7.0	16.8	0
VI	S	24	55.8	7.2	10.3	DRL	S	49	21.0	10.3	64.8
VI		31	55.5	20.1	29.2	DRL		26	8.7	14.2	0
VI	D	31	56.3	33.6	0	DRL	D	38	8.3	16.1	0
VI		20	56.0	21.4	35.7	DRL		50	5.1	17.5	0
		53						69			
Schedule	Delay	Sessions	SR	Overall Rate	Local Rate	Schedule	Delay	Sessions	SR	Overall Rate	Local Rate
VI		25	57.3	34.4	38.7	VI		58	59.1	60.3	64.3
VI	S̄	29	56.8	31.9	80.5	VI	S	21	58.2	46.4	1.3
VI		20	57.0	22.9	38.9	VI		53	57.8	49.6	58.6
VI	D	24	55.8	19.2	0	VI	S̄	37	57.5	47.5	69.5
VI		42	56.7	22.3	31.0	VI		21	57.7	42.3	47.1

differ by more than 3% from the means of the first and last three sessions during the six-session period. The signaled delay condition (labeled S in Table 1) was a chain VI 60-sec FT .5-sec schedule in which responding during the VI produced, on the average of once a minute, a .5-sec blackout in the chamber followed by food presentation. During the unsignaled delay condition (labeled S̄ in Table 1), which was a tandem VI 60-sec FT .5-sec schedule, the stimulus conditions in the chamber were identical during the VI and .5-sec delay interval. The response delay condition (labeled D in Table 1) was a tandem VI 60-sec DRO .5-sec schedule wherein each response during the delay prolonged the delay to ensure a 5-sec interval between the last response and reinforcement.

Birds 11 and 51 received signaled and unsignaled delays imposed during both VI and DRL schedules. In addition, Bird 11 received

the response delay condition imposed during VI and Bird 51 received it during DRL. Birds 53 and 69 were used to replicate either the signaled/unsignaled delay comparison (Bird 69) or the unsignaled/response delay comparison (Bird 53). Each delay condition was preceded and followed by the immediate reinforcement baseline condition as noted in the table.

RESULTS

Figures 2 and 3 show the response rates of each bird during the last six (stable) sessions of each baseline and delay condition when the VI (Figure 2) and DRL (Figure 3) schedules were in effect. Figure 4 summarizes these response rates, averaged and expressed as a percentage of the mean of the baseline preceding and following each condition. The variability of these rates is shown in Figures 2 and 3. Re-
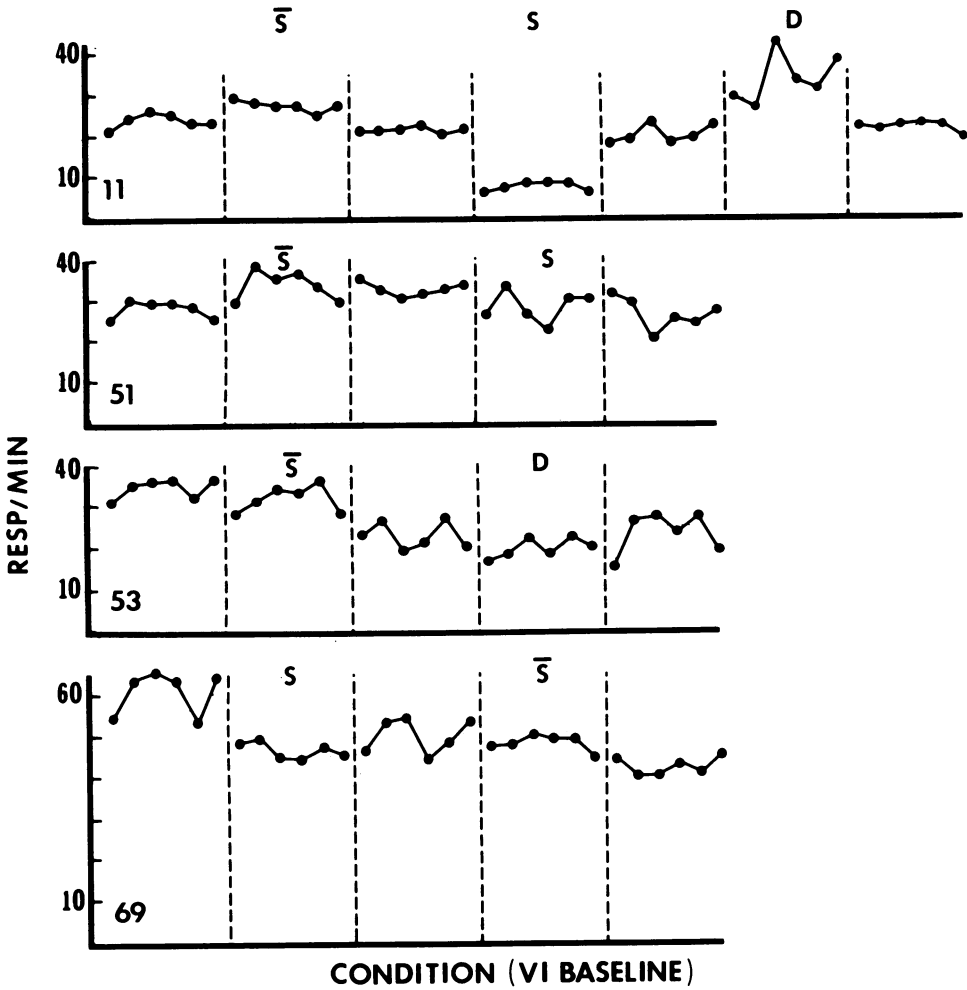
Fig. 2. Responses per minute during each of the last six sessions of each condition for each bird when the VI schedule was in effect. Baseline VI conditions are not labeled. Signaled, unsignaled, and response delay conditions respectively are labeled S, S̄, and D.
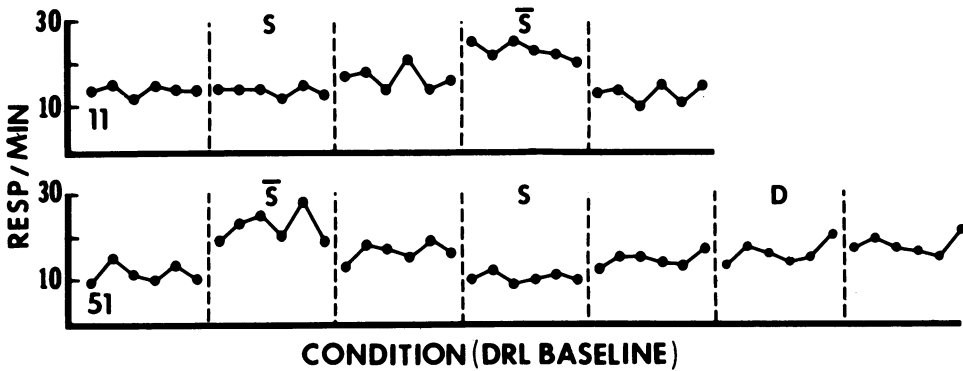

Fig. 3. Responses per minute during each of the last six sessions of each condition for each bird when the DRL schedule was in effect. Baseline DRL conditions are not labeled. Signaled, unsignaled, and response delay conditions respectively are labeled S, S̄, and D.
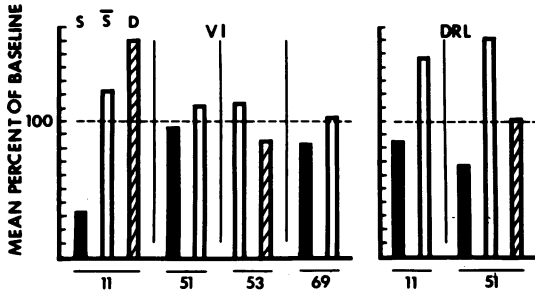
Fig. 4. Mean response rates expressed as a percent of the mean of the baseline response rates preceding and following each delay condition when the delays were imposed during VI (left graph) and DRL (right graph) schedules. Solid, open, and dashed bars depict signaled, unsignaled, and response delay conditions. The dashed line depicts the mean baseline response rate. Points above this line are increases from baseline and points below this line are decreases from baseline.

sponse rates during the unsignaled delay were higher, to varying degrees, than during the immediate reinforcement baseline condition and response rates during the signaled delay were lower than during the immediate reinforcement conditions. Mean rates during the response delay condition were higher than the mean of the pre- and post-manipulation baseline rate for Bird 11, lower for Bird 53, and unchanged from baseline for Bird 51.

Figures 5 and 6 show the percentage of total responses during the last 6 sessions of each condition that fell in successive .5-sec IRT intervals (bins). Figure 5 shows these data when VI was used. For all birds, the percent of total responses occurring during the 0 to .5-sec time interval was relatively low during the immediate reinforcement condition, increased during the unsignaled and response delay conditions, and decreased during the signaled delay condition. Changes in the other bins were unsystematically related to the type of delay. Figure 6 shows that similar changes occurred when DRL was used to maintain responding. In general, a greater percentage of the total IRTs occurred during the 0 to .5-sec interval under the unsignaled and response delayed conditions than with the signaled delay. Bird 51 did not increase its frequency of 0 to .5-sec IRTs during the response delay condition.

Local (terminal) response rates immediately preceding reinforcement were obtained under the different conditions, although equipment limitations necessitated somewhat different measurement procedures in the different con-

ditions. Responding during the .5 sec before reinforcement was, by definition, zero during the DRL baseline (excluding the reinforced response) and during the response delay condition. Terminal response rates during the VI baseline were measured during an interval that was initiated by the completion of the interreinforcer interval of the constant probability distribution and terminated .5 sec later. Terminal response rates during the signaled and unsignaled delays were measured during the .5-sec delay interval. These mean terminal response rates for the last six sessions of each condition are shown in Table 1, as well as the mean overall response rates for the last six sessions of each condition (cf. Figures 2 and 3). Terminal rates during VI were somewhat higher than overall response rates, perhaps because of pauses at the beginning of the interval. These rates during the signaled delay varied in relation to overall response rates with Bird 51 consistently responding during the .5-sec blackout and Bird 69 rarely responding during the blackout. During the unsignaled delay the terminal rates were higher than in any other condition and they also exceeded overall response rates, in most instances by considerable amounts.

Under the VI schedule, reinforcement frequency did not change between each of the delay conditions nor between the immediate and delayed reinforcement conditions. Table 1 shows that during the DRL schedules reinforcement frequency was higher during the signaled delay than during the immediate, unsignaled delay, and response delayed reinforcement conditions. Reinforcement frequency during these latter three conditions did not differ systematically from one another.

DISCUSSION

Response rates covaried with the IRT distribution in several ways. With the signaled delays, rates were low relative to the baseline condition and the modal IRTs shifted toward longer durations relative to the immediate reinforcement schedules. Unsignaled delays generally increased response rates and, without exception, increased the relative frequency of 0 to .5-sec IRTs from the baseline schedules. Except for Bird 51, this latter relation was true also of the response delays. These changes in response rates and IRT distribution shifts
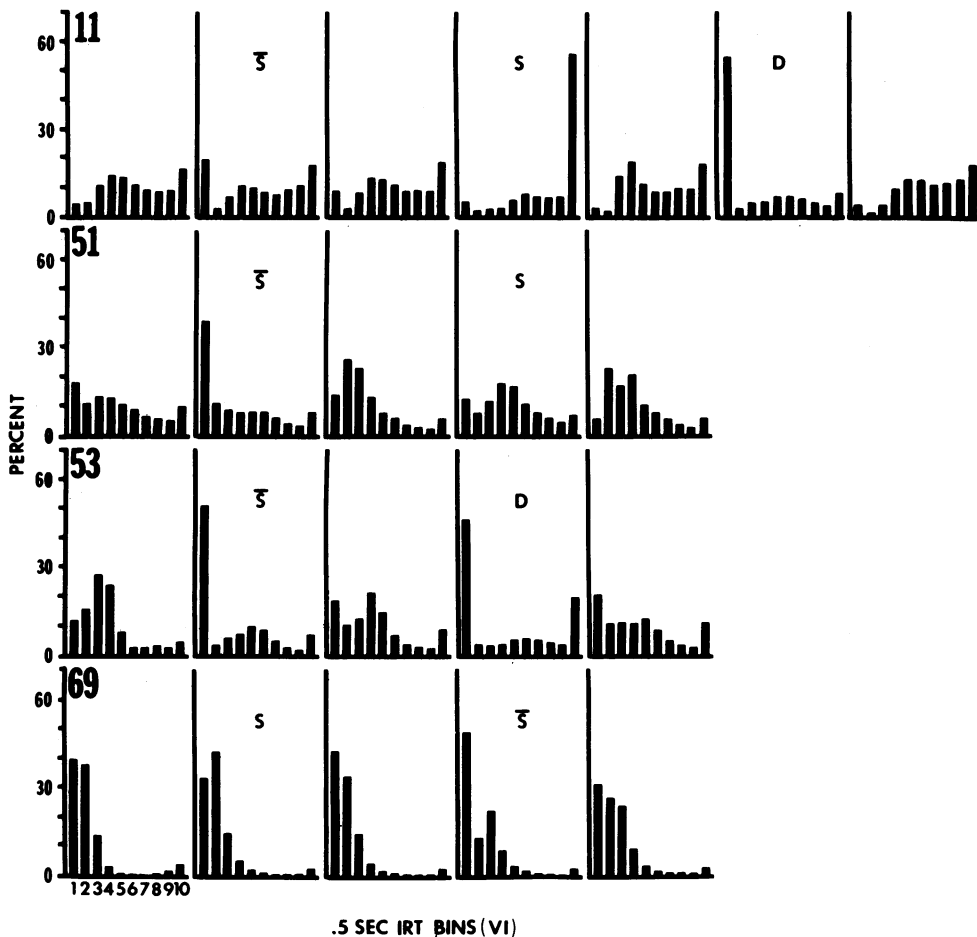
Fig. 5. Percent of total responses during the last six sessions of each condition in successive .5-sec IRT intervals (bins) when signaled (S), unsignaled (S̄), and response delay (D) conditions were imposed during VI schedules. Graphs without labels above them indicate baseline conditions. From left to right successive conditions are depicted as they occurred sequentially during the experiment.

toward and away from the 0 to .5-sec IRT bin under the different conditions were in the directions suggested in the introduction.

The premise of the experiment was that .5-sec unsignaled delays allow high local rates of responding (bursts, defined by short IRTs) to occur that otherwise are constrained by such intruding stimuli as the reinforcer or signals accompanying delay intervals. These local rate increases are reflected as increases in overall response rates. One potential limitation of this account is that the IRT distributions provide only indirect evidence of bursts of responses in the sense of sequences of short IRTs. In addition to findings indicating that short IRTs are more likely to be followed by short,

rather than long, IRTs (Blough & Blough, 1968), the local rate data in Table 1 provide direct evidence of bursts of responses. That is, key-pecking rates are substantially higher in a .5-sec interval after a peck (unsignaled delay condition) than in an interval chosen independently of whether a peck initiated the interval (immediate reinforcement condition).

Another potential limitation on this account is that the relation between frequency of 0 to .5-sec IRTs and response rates is correlational. That is, a change in one independent variable, the type of delay of reinforcement procedure used, produces changes in both of these measures. Since the two measures often covary, it could be argued that it is difficult
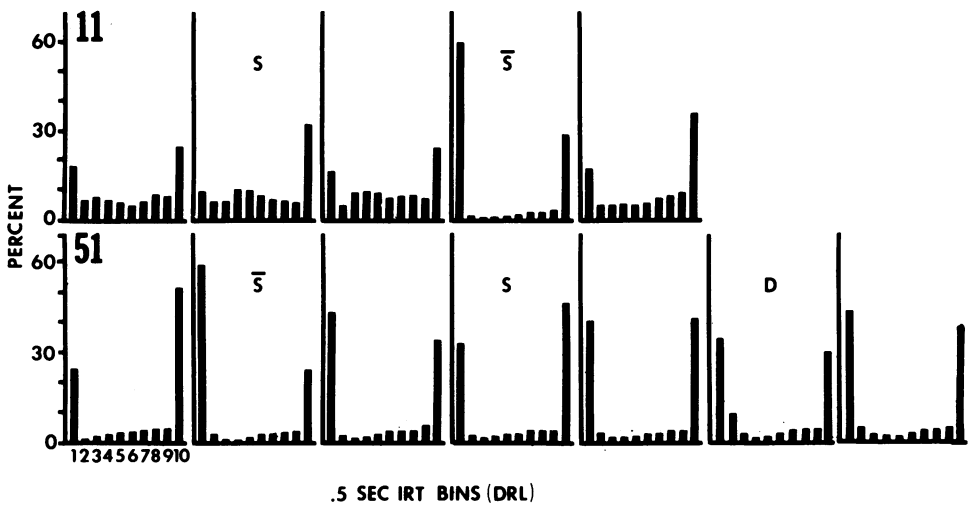
Fig. 6. Percent of total responses during the last six sessions of each condition in successive .5-sec IRT intervals (bins) when signaled (S), unsignaled (S̄), and response delay (D) conditions were imposed during DRL schedules. Graphs without labels above them indicate baseline conditions. From left to right successive conditions are depicted as they occurred sequentially during the experiment.

to determine whether the rate changes cause or are caused by changes in frequency of short IRTs. That the increase in short IRTs is an artifact of rate increases is contradicted by some of the data. For example, Bird 69 showed little change in overall response rates between the immediate and unsignaled delay condition but the frequency of 0 to .5-sec IRTs still increased during the delay conditions relative to the preceding and following immediate reinforcement conditions. Bird 53 showed a similar change in IRT distribution during both the unsignaled and response delay conditions with little change in overall rate from the unsignaled delay to the following immediate reinforcement baseline and a decrease in overall rate from baseline during the response delay condition.

Increases in overall response rates can occur if the number of 0 to .5-sec IRTs increases and other, longer, IRTs either remain constant or decrease. Overall rates might not increase if the number of 0 to .5-sec IRTs increase but the number (relative frequency) of longer IRTs also increase. For example, Bird 69 increased the relative frequency of 0 to .5-sec IRTs during the unsignaled delay. However, compared to the preceding VI baseline condition, there was a substantial decrease in the proportion of IRTs in the .5 to 1-sec bin and increases in the

proportion of IRTs in several of the other, longer, IRT bins. Thus, any response rate increase which might have occurred due to increases in the frequency of 0 to .5-sec IRTs was counteracted by the increased frequency of longer IRTs. Bird 53 increased the proportion of both 0 to .5-sec IRTs and several longer IRTs during the response delay condition relative to the immediate reinforcement condition. Again, the effect of this bimodal increase was to negate a response rate increase and actually produce a rate decrease.

Another factor that could have affected the responding of Bird 53 during the response delay condition is the delay of reinforcement gradient itself. Under the response delay condition, the presence of a delay that is unsignaled permits potential response bursts to be completed prior to reinforcement. However, the last response in a burst is always separated from reinforcement by .5 sec. The absence of a signal during the delay allows the local response rates to increase, with an accompanying increase in short IRTs. The lower-than-baseline overall response rates may be due to a delay-of-reinforcement effect in that the DRO contingency ensures a .5-sec delay between the last response and reinforcement. In cases where response rates did not increase or increased marginally during the brief unsignaled delay

condition without the DRO contingency (Birds 53 and 69), a similar process might operate. That is, depending on when the last response prior to reinforcement occurred, any one delay interval could be as long as .5 sec. Because even the longest obtained delays would still be brief, any response rate reduction caused by the delay should be relatively small.

The failure of Bird 51 to increase 0 to .5-sec IRTs during the response delay condition could have resulted from the competing processes of burst completion and delay effects. It also may be significant that the relative frequency of 0 to .5-sec IRTs during the preceding baseline was substantially higher than those of any other subject under any other condition preceding an unsignaled or response delay condition. The failure of 0 to .5-sec IRTs to increase could be a limitation imposed by the already-high relative frequency of these IRTs during baseline.

Schedules providing immediate reinforcement implicitly are considered "optimal" conditions for response maintenance relative to such conditions as delayed reinforcement. However, in many instances in the present experiment briefly delayed reinforcement maintained higher rates of responding and/or shorter IRTs than did immediate reinforcement. These results suggest that a schedule of immediate reinforcement can actually constrain responding relative to conditions historically and procedurally considered less than optimal for response maintenance. The degree of constraint may differ for different schedules. For example, imposing brief unsignaled delays during the DRL schedule resulted in a greater proportion of 0 to .5-sec IRTs and generally proportionally greater response rate increases from the baseline than did such delays imposed during VI (cf. Birds 11 and 51). With DRL schedules, all responses in a burst, except the first, are ineligible for reinforcement. Variable-interval schedules do not impose such a restriction so that bursting is less constrained under VI than under DRL schedules. When brief unsignaled delays are added to both, bursting and rate increases are more likely to occur during DRL than during VI.

The presence or absence of constraints on local response rates and response bursting is an empirical description of the variables responsi-

ble for changes in response rates under the different conditions. Theoretical explanations of why these variables have such effects include adventitious reinforcement of short IRTs, removal of selective reinforcement of long IRTs, and the development of variable delays of reinforcement of different responses. Sizemore and Lattal (1978) suggested that the short IRTs that develop during brief unsignaled delays are reinforced adventitiously by their close temporal proximity to food delivery. These reinforced IRTs increase in frequency, resulting in an increased overall response rate. The local rate data in Table 1 are consistent with this account in that response rates were considerably higher immediately prior to reinforcement during unsignaled delays, reflecting the predominance of short IRTs, than the overall rates. This effect was not found with either immediate reinforcement or signaled delays. However, a similar relation between reinforced IRTs and predominant IRTs in the case of interval schedules delivering immediate reinforcement has not been supported consistently (Anger, 1956; Blough & Blough, 1968; Reynolds & McLeod, 1970). A second account was suggested by Dews (1969) who showed that unsignaled delays eliminate the preferential reinforcement of long IRTs that characterize interval schedules. Thus, shorter IRTs might increase, with a resultant increase in response rates, simply because conditions maintaining the selective reinforcement of longer IRTs is eliminated. The difference between the accounts of Sizemore and Lattal (1978) and Dews (1969) seems to be one of emphasis rather than kind in that the former assumes a more active behavioral process, the action of adventitious reinforcement, while the latter assumes one that is more passive. A third account emphasizes the importance of delay of reinforcement of response preceding the one contiguous with reinforcement (Catania, 1971). This suggests that response rate increases that occur when short IRTs predominate are due to the shorter delay of reinforcement of responses preceding the one closest to reinforcement.

Although this experiment does not provide a basis for selecting among these, or other, theoretical interpretations, it does provide a necessary empirical prelude for such selection. The data indicate that accounts of delayed re-

inforcement effects must consider not only problems of signal nature and function and of response-reinforcer contiguity, but must also consider more complex functional relations that develop from the procedures used to impose delays of reinforcement.

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