CHANGES IN FUNCTIONAL RESPONSE UNITS WITH BRIEFLY DELAYED REINFORCEMENT

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In two experiments, key-peck responding of pigeons was compared under variable-interval schedules that arranged immediate reinforcement and ones that arranged unsignaled delays of reinforcement. Responses during the nominal unsignaled delay periods had no effect on the reinforcer presentations. In Experiment 1, the unsignaled delays were studied using variable-interval schedules as baselines. Relative to the immediate reinforcement condition, 0.5-s unsignaled delays decreased the duration of the reinforced interresponse times and increased the overall frequency of short (<0.5 -s) interresponse times. Longer, 5.0-s unsignaled delays increased the duration of the reinforced interresponse times and decreased the overall frequency of the short interresponse times. In Experiment 2, similar effects to those of Experiment 1 were obtained when the 0.5-s unsignaled delays were imposed upon a baseline schedule that explicitly arranged reinforcement of short interresponse times and therefore already generated a large number of short interresponse times. The results support earlier suggestions that the unsignaled 0.5-s delays change the functional response unit from a single key peck to a multiple key-peck unit. These findings are discussed in terms of the mechanisms by which contingencies control response structure in the absence of specific structural requirements.

Key words: unsignaled delay of reinforcement, variable-interval schedules, reinforced IRTs, response units, response structure, interresponse times, delay duration, key peck, pigeons

Contingencies between responses and their consequences are central to the organization of behavior (e.g., Baer, 1982). Because operants have been described both procedurally and functionally (Catania, 1973), it is possible to identify at least two bases for defining response units. One is in terms of experimental arrangements (e.g., one key peck or one wheel turn equals one unit). The other basis for response units is functional. These functional units result from experimental arrangements but are not explicitly required by the contingencies. Procedurally defined units of behavior have included some that are comprised of multiple responses over extended (i.e., noninstantaneous) time frames. For example, Hawkes and Shimp (1975) demonstrated control over response patterns within 5-s intervals by arranging differential consequences for different patterns (see also Zeiler, 1970). Similar effects have been routinely examined in briefer, but still noninstantaneous, time frames in the many demonstrations of how required interresponse

times (IRTs) for reinforcement exert control over the overall distributions of IRTs (e.g., Kramer & Rilling, 1970).

Interresponse times also can be formed into functional units in the absence of IRT requirements. For example, variable-interval (VI) schedules of reinforcement have been shown to differentially reinforce longer IRTs although reinforcement is not dependent upon any particular IRT class (Morse, 1966). Lattal and Ziegler (1982) showed that the frequency of short IRTs increased when 0.5-s unsignaled delays of reinforcement were imposed during both VI and differential-reinforcement-of-low-rate (DRL) schedules. Equivalent brief delays signaled by blackout typically decreased the frequency of short IRTs relative to the corresponding immediate-reinforcement condition. These changes in response patterns under the signaled and unsignaled delays were taken as supporting Sizemore and Lattal's (1978) suggestion that both immediate reinforcement and delays that are signaled remove opportunities to respond, occasionally truncating what otherwise might be a burst of responses (see Lattal & Ziegler, 1982, Figure 1). However, with brief unsignaled delays, brief IRTs subsequent to the one that initiates the delay can occur during the delay. With a fixed-time nominal delay of 0.5 s, bursts are more likely to occur and therefore will

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coterminate relatively close to food delivery. Thus a major effect of brief unsignaled delays was suggested to be one of changing the functional unit of behavior from a single key peck to a burst of several key pecks.

Lattal and Ziegler's (1982) data were only suggestive with respect to changes in functional units. Specifically, in addition to the overall increases in short IRTs, they reported that local response rates during the 0.5-s unsignaled fixed-time delays were considerably higher than the overall response rates. However, these data do not indicate which response sequences were reinforced, nor do they indicate how changes in overall patterns of responding changed as a function of changes in the reinforced units. The present Experiment 1 provides a more complete analysis of the effects outlined by Lattal and Ziegler (1982) and Sizemore and Lattal (1978). Experiment 2 explores the effects produced when a relatively large number of brief IRTs (bursts) already occurred in the immediate-reinforcement baseline. In addition, both experiments compare the effects of brief (0.5-s) unsignaled delays to those of longer (5-s) unsignaled delays to assess whether the effects obtained with brief delays are generic effects of unsignaled delays of reinforcement or are limited to a small range of durations.

EXPERIMENT 1

Events occurring temporally close to reinforcement were suggested by Lattal and Ziegler (1982) and by Sizemore and Lattal (1978) to be significant in the reorganization of behavior under contingencies of briefly delayed reinforcement. The first experiment examined the actual sequences of responses that occurred just prior to each reinforcer. Of particular interest was the relation between these sequences and the overall distribution of responses.

METHOD

Subjects

Three naive White Carneau pigeons were maintained at approximately 80% of their free-feeding weights. Water and Palmetto health grit were available continuously in the home cages.

Apparatus

The experiment was conducted in an operant conditioning chamber for pigeons with

internal dimensions of 30.5 cm long by 30 cm wide by 38.5 cm high. The 2.5-cm-diameter response key was located on the work panel 7.8 cm from the right wall and 22 cm from the floor of the chamber. It was transilluminated by a 28-V AC bulb at all times except during the delivery of reinforcers. A force of at least 0.15 N was required to operate the key. General illumination of the chamber was provided by a white 7-W 110-V AC bulb. Reinforcers consisted of 4-s access to Purina® 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. Experimental conditions were controlled from an adjacent room by a PDP 8/a® minicomputer using SuperSKED® software.

Procedure

Key-peck responses of each bird were hand shaped, after which each bird received preliminary training on a series of VI schedules of increasing values over several sessions. The birds then were trained on a tandem variable-time 60-s fixed-interval 0.5-s (tandem VT 60-s FI 0.5-s) schedule. In a tandem schedule, completions of two or more successive schedule components, each accompanied by the same stimulus, are required before each reinforcer presentation. The VT component of the tandem schedules consisted of 24 intervals, and used a modified Fleshler and Hoffman (1962) progression of 25 intervals in which the shortest interval was omitted (making the shortest interval in the distribution 3.72 s) and the value of the longest interval was then modified to maintain the average at 60 s. The shortest interval was omitted so that a data-collection period ("sampling period") could be used, which always started 3 s before the VT was scheduled to end. The VT values were selected randomly without replacement from the entire list of values. During the delay conditions, the schedule consisted of a tandem variable-interval 60 s fixed time t s (tandem VI 60 s FT t s). The VI component used the same progression of values as the VT component. The FT t s was the delay component, during which responses had no scheduled consequence.

The sequence of conditions and corresponding numbers of sessions for each subject are shown in Table 1. Delay values of 0.5 and 5 s were studied. The 0.5-s delay previously has

Table 1

Sequence of experimental conditions, number of sessions, responses per minute, session length in minutes, and obtained delays of reinforcement in seconds for each subject in the first experiment. Each of these latter three measures is the mean computed over the last six sessions of the specified condition. The nominal mean interval for the VI and VT schedules was 60 s. The nominal interval for the FI schedule was 0.5 s.

Subject	Condition	Number of sessions	Responses per minute	Session length (minutes) ^a	Obtained delays (seconds)
506	tandem VT FI	37	40.22	47.26	—
	tandem VI FT 0.5 s	21	36.87	45.67	0.38
	tandem VT FI	21	46.85	45.25	—
	tandem VI FT 5 s	21	18.84	49.21	1.78
	tandem VT FI	22	38.21	45.38	—
	tandem VI FT 0.5 s	72	46.93	45.85	0.31
524	tandem VT FI	28	39.93	45.48	—
	tandem VT FI	67	33.43	47.11	—
	tandem VI FT 0.5 s	24	29.83	45.22	0.38
	tandem VT FI	23	43.15	42.89	—
	tandem VI FT 5 s	45	4.38	58.86	4.11
758	tandem VT FI	38	36.69	45.75	—
	tandem VT FI	31	56.84	45.52	—
	tandem VI FT 0.5 s	21	45.86	43.24	0.29
	tandem VT FI	30	40.87	44.87	—
	tandem VI FT 0.5 s	28	48.71	45.02	0.23
	tandem VT FI	23	43.00	45.70	—

^a Session length includes time of reinforcer deliveries.

been shown to change the distributions of IRTs. The 5-s delay was selected as a comparison value (control condition) to assess whether the effects of the brief delay on IRT distributions resulted from the imposition of an unsignaled delay per se or from the imposition of a brief unsignaled delay. All subjects were returned to the immediate-reinforcement baseline condition after each delay condition. Bird 758 became ill following stability on the third exposure to the baseline condition and was removed from the experiment after five sessions of exposure to the 5-s delay condition.

Each condition was in effect for a minimum of 20 sessions, and conditions were changed only when response rates were stable. Stability was defined as six consecutive sessions in which the means of the first and last three sessions did not differ by more than 3% from the six-session mean. Sessions were conducted 5 days per week, and each session was terminated after the 40th reinforcer.

RESULTS

Table 1 provides the average response rates for each subject for the last six sessions of each condition. The 5-s delays always resulted in decreased response rates relative to the immediate-reinforcement baseline conditions. The

0.5-s delays produced inconsistent changes in response rates, with an individual subject showing both increases and decreases in response rates relative to baseline during different exposures to the same condition. Response rates during the baseline conditions sometimes did not recover to previous levels after exposure to a delay condition. For two birds, higher response rates occurred (relative to the first immediate-reinforcement baseline) during a return to baseline after their initial exposure to the 0.5-s delay condition. For the third bird (758), response rates decreased during this return to baseline. For the two birds (506 and 758) that were exposed to a second 0.5-s delay condition, response rates for the baseline following the second 0.5-s delay condition recovered to levels very close to the preceding baseline condition. There was also a lack of recovery of baseline response rates after exposure to the control conditions with 5-s delays. For both birds exposed to the 5-s delays (506 and 524), response rates were lower relative to the preceding baseline during the baseline following the condition with 5-s delays.

Figure 1 shows the overall IRT distributions for each subject averaged over the last six sessions of each condition. Bin 10 includes IRTs ≥ 4.5 s. Percentages less than 0.5 were

Fig. 1. Percentage of total IRTs averaged over the last six sessions of each condition in successive 0.5-s IRT bins. Baseline conditions with immediate reinforcement are indicated by a B, and 0.5-s and 5-s delay conditions are indicated by 0.5 s D and 5 s D, respectively. Successive conditions for each subject are depicted from left to right as they occurred sequentially during the experiment.

rounded to zero. During the baseline conditions the IRT distributions in general were bimodal for 1 subject (506) and unimodal for the other 2. The IRT distributions tended to spread out toward both the shorter and the longer bins during the 0.5-s delay conditions. The IRT distributions during the 5-s delay conditions were unimodal for each subject, with few IRTs occurring in the shortest bins. The IRT data from Figure 1 also were transformed to interresponse times per opportunity (IRTs/op; Anger, 1956). This statistic reiterated the findings depicted in Figure 1; that is, the relative frequency of short IRTs increased with brief delays and decreased with the 5-s delay condition. These data are not shown because they revealed no systematic relations beyond those shown in Figure 1.

Figure 2 shows the mean reinforced IRT (i.e., the last IRT before the reinforcer presentation) averaged over all 40 reinforcers during a session and over the last six sessions of each condition. The 5-s delay conditions increased the mean reinforced IRT over baseline values for the 2 subjects exposed to these delays. The 0.5-s delay conditions decreased the mean reinforced IRT for each subject. Only for Subject 524 did the reinforced IRT fail to increase during the return to baseline following the 0.5-s delay condition.

Figure 3 provides distributions of the rein-

forced IRTs. These distributions again include all 40 reinforcers during a session and are averaged across the last six sessions of each condition. Bin 10 included all IRTs ≥ 4.5 s. Percentages less than 0.5 were rounded to zero. The data show that the 0.5-s delay conditions

Fig. 2. Mean reinforced IRTs (in seconds) averaged over the last six sessions of each condition for each subject. Immediate-reinforcement baseline conditions are indicated by a B, and delay conditions are indicated by a D, with the value of the nominal delay indicated at the top of the bar. Successive conditions are depicted from left to right as they occurred sequentially during the experiment.

Fig. 3. Percentage of reinforced IRTs averaged over the last six sessions of each condition in successive 0.5-s IRT bins. Immediate-reinforcement baseline conditions are indicated by a B, and 0.5-s and 5-s delay conditions are indicated by 0.5 s D and 5 s D, respectively. Successive conditions for each subject are depicted from left to right as they occurred sequentially during the experiment.

shifted the distributions toward the shortest bin relative to the baseline conditions, and the 5-s delay conditions produced shifts toward the longer bins of the distributions relative to the baseline conditions. The reinforced-IRT data from Figure 3 also were transformed to IRTs/op. They reiterated the findings depicted in Figure 3 and therefore are not shown.

Figure 4 illustrates how the patterns of responses during the sampling periods changed as a function of the delay conditions (the sampling periods are described in the first paragraph of the procedure section). Figure 4 presents distributions of the number of responses per burst that occurred, expressed as an average number per sampling period. A burst was defined in terms of consecutive responses separated by less than 0.5 s. For all subjects, the 0.5-s delay conditions increased the numbers of bursts composed of more than two responses. The number of bursts composed of two responses (i.e., a single IRT) increased for 2 subjects and decreased for 1 (Bird 506). Even in the instance in which single-IRT bursts decreased, the absolute numbers of short IRTs increased because of the increases in the number of bursts composed of multiple IRTs. The 5-s delay control conditions decreased the number of short IRTs. This was reflected in decreases across bursts composed of both single and multiple IRTs.

Figure 5 presents bursts per opportunity for bursts comprised of different numbers of IRTs during the sampling periods. That is, given the total number of IRTs less than 0.5 s, the number of opportunities for bursts comprised of each number of IRTs (i.e., the burst size) was calculated by dividing the total number of IRTs less than 0.5 s by the number of IRTs within each size burst. To produce the bursts per opportunity, the number of obtained bursts of each size was then divided by the number of opportunities for each size burst. Thus, this statistic provides a measure of changes in the size of bursts irrespective of the changes in the absolute number of the short IRTs. Figure 5 shows that for 2 subjects (506 and 758) the number of bursts per opportunity decreased for single-IRT bursts and increased for multiple-IRT bursts during the 0.5-s delay conditions relative to the immediate-reinforcement baseline. This indicates that the number of multiple-IRT bursts increased more than would be expected simply from increases in the overall frequency of short IRTs. Subject 524 showed increases in the absolute number of bursts of all sizes (see Figure 4), but the burst-per-opportunity transformation showed little change in the burst size after changes in absolute numbers of short IRTs were controlled. The data for each of the subjects exposed to the 5-s delay control condition show

Fig. 4. Distributions of number of consecutive responses separated by less than 0.5 s (number of responses per burst) that occurred during the sampling periods, averaged over the last six sessions of each condition for each subject. Baseline conditions with immediate reinforcement are indicated by a B, and 0.5-s and 5-s delay conditions are indicated by 0.5 s D and 5 s D, respectively. Successive conditions are depicted from left to right as they occurred sequentially during the experiment.

that the number of bursts per opportunity usually decreased for multiple-IRT bursts and either stayed the same or increased for single-IRT bursts.

Figure 6 presents the actual delays between

the last response and the onset of reinforcers for all delay conditions. Data include the 40 delays per session and were averaged across the last six sessions of each delay condition. The nominal delays are divided into 10 equal

Fig. 5. Bursts per opportunity for bursts comprised of different numbers of IRTs (i.e., burst size) that occurred during the sampling periods, averaged over the last six sessions of each condition. Immediate-reinforcement baseline conditions are indicated by a B, and 0.5-s and 5-s delay conditions are indicated by 0.5 s D and 5 s D, respectively. Successive conditions for each subject are depicted from left to right as they occurred sequentially during the experiment.

bins, each bin being 0.05 s in duration during the 0.5-s delay conditions and 0.5 s in duration during the 5-s delay conditions. During the 0.5-s delay conditions, the delay distributions for all 3 subjects tended to be bimodal, with the obtained delays frequently occurring within 0.05 s of the full 0.5-s nominal delay value. During the 5-s delay conditions, for Bird 524 most of the obtained delays were within 0.5 s of the full 5.0-s nominal delay. For Bird 506, most obtained delays were between 0 s and 2.5 s.

DISCUSSION

The absence of consistent effects of brief unsigned delays of reinforcement in terms of molar overall response rates yielded to systematic patterns of responding at a different, more fine-grained, level of analysis. Orderly fine-grained effects of such delays were observed with both overall and reinforced-IRT distributions, with local patterns of responding during a period just prior to food delivery, and with response-reinforcer temporal contiguity. In particular, these data show that imposing brief unsigned delays decreases the duration of the last IRT before food presentations. These short IRTs increased in frequency, relative to the immediate-reinforcement baseline, and decreased in frequency when the immediate-reinforcement baseline was reinstated. In addition, many of the short reinforced IRTs

observed during the brief unsigned delay procedure occurred with close to the full 0.5-s nominal delay, and few occurred precisely contiguous to the food presentations. The actual delays, therefore, were variable and, in many cases, surprisingly long.

The two conditional probability measures, IRTs/op and bursts/op, take into account changes in the absolute numbers of, respectively, IRTs and IRTs less than 0.5 s across all behavioral categories or bins. If the effects of brief delay were simply to increase the absolute numbers of all IRT categories, the shapes of these distributions would be unchanged from the immediate-reinforcement baseline condition. To the extent that the various categories or bins changed differentially, the shapes of the conditional probability distributions also changed.

EXPERIMENT 2

In the first experiment, and in previous experiments using VI schedules in which briefly delayed reinforcement was either shown or suggested to differentially reinforce short IRTs, no particular IRT was required for reinforcement. In the second experiment, we examined the effects of brief unsigned delays within VI schedules when the reinforcers were dependent on short IRTs. We reasoned that the high frequency of short IRTs likely to be pro-

duced by an IRT reinforcement contingency might preclude further increases in the number of short IRTs, resulting in the more typical delay effect of reduced response rates. Alternatively, the effects of the brief unsignaled delays could add generality to the effects found in Experiment 1 if similar results were found.

METHOD

Subjects and Apparatus

Birds 506 and 524 from the first experiment served as subjects. The apparatus was as described for the first experiment.

Procedure

Following the final condition of the first experiment, the schedule for each subject was changed to a VI 60-s schedule in which the first IRT of less than 0.5 s that occurred after the interreinforcer interval lapsed produced 4-s access to mixed grain. In other respects, the VI schedule was identical to that described in Experiment 1. The delay conditions consisted of tandem VI 60-s FT *t*-s schedules. The VI component was as described above. When the VI interreinforcer interval lapsed, the first IRT of less than 0.5 s initiated a fixed-time period that terminated with food delivery. Therefore all reinforced IRTs were less than 0.5 s. Responses during the FT component were recorded but were without consequence.

The sequence of conditions and numbers of sessions for each subject are shown in Table 2. Two delay values (0.5 s and 5 s) were studied. As in Experiment 1, 5 s was selected as a comparison value to ensure that the effects of the brief delay resulted from the brevity of the delay rather than from the imposition of an unsignaled delay per se. Each delay condition was in effect for a minimum of 20 sessions and was preceded and followed by the VI immediate-reinforcement-of- <0.5 -s-IRTs schedule. Conditions were changed only when response rates met the stability criterion described in Experiment 1. Sessions occurred 5 days per week and each terminated after the 40th reinforcer.

RESULTS

A comparison of Figures 1 and 7 reveals that the change of baseline schedule changed the frequency of short IRTs. The last baseline shown in Figure 1 immediately preceded the

first baseline shown in Figure 7. For Bird 506 there was a 24% increase in the frequency of 0.0 to 0.5-s IRTs and for Bird 524 there was a 31% increase in these IRTs.

Figure 7 shows the overall IRT distributions for each subject averaged over the last six sessions of each successive condition. The IRT distributions during the baseline conditions were roughly bimodal for both subjects, with the largest mode occurring in the shortest IRT bin. During the 0.5-s delay conditions, the IRT distributions usually remained bimodal with the mode in the shortest IRT bin increased over the baseline conditions. The remaining bins in the distributions tended to flatten out relative to the baseline conditions, and the second mode moved to the longer bins. During the second exposure to the 0.5-s delay condition, the IRT distribution of Bird 524 was unimodal with an almost flat distribution of IRTs after the first mode in the shortest bin. During the 5-s delay conditions the IRT distributions remained bimodal, with the mode in the shortest bin decreased and the second mode moved toward the larger bins relative to baseline conditions. The data from Figure 7 were transformed to IRTs/op, which also showed that the relative frequency of IRTs in the smallest IRT bin increased with brief delays and decreased with the longer control delay conditions. These data are not shown because they revealed no systematic relations beyond those shown in Figure 7.

Table 3 shows that, during the 0.5-s delay conditions, the number of consecutive IRTs shorter than 0.5 s increased substantially relative to those in the immediate-reinforcement baseline conditions. As many as eight consecutive responses (seven IRTs <0.5 s) occurred and four- to five-response bursts were relatively frequent during the 0.5-s delay conditions. By contrast, very few bursts occurred during the 5-s delay conditions.

Figure 8 presents bursts per opportunity, calculated as described in Experiment 1, for bursts comprised of different numbers of IRTs for all bursts during the sessions. During the 0.5-s delay conditions, the number of single-IRT bursts declined for both subjects, and the number of bursts comprised of three or more IRTs increased for both subjects. The 5-s delay control condition tended to reduce the number of multiple-IRT bursts, moving the distributions of bursts per opportunity toward the shorter bursts.

Fig. 6. Percentage of obtained delays, in 10 successive delay bins, averaged over the last six sessions of each delay condition for each subject. Each delay bin is 0.05 s in duration for the 0.5-s delay conditions and 0.5 s in duration for the 5-s delay conditions. The values of the nominal delays are indicated above the distributions. The 0.5-s delay condition depicted in the left graphs occurred first.

Figure 9 presents the actual delays between the last response and the onset of the reinforcer for all delay conditions. Data include the 40 delays per session and were averaged across the last six sessions of each delay condition. The nominal delays are divided into 10 equal bins, each bin being 0.05 s in duration during the 0.5-s delay conditions and 0.5 s in duration

during the 5-s delay control conditions. During the 0.5-s delay conditions the delay distributions for both subjects tended to be bimodal, with one mode occurring within 0.05 s of the full 0.5-s nominal delay and the other mode occurring at about 0.15 s to 0.25 s. During the 5-s delay control conditions, both birds obtained the majority of the delays within 0.5 s

Table 2

Sequence of experimental conditions, numbers of sessions, responses per minute, session length in minutes, and obtained delays of reinforcement in seconds for each subject in the second experiment. Each of these last three measures is a mean computed over the last six sessions of a given condition. The nominal mean interval for the VI was always 60 s and an IRT shorter than 0.5 s was always required at the end of the interreinforcer interval to initiate food delivery (in the case of the VI schedule) or to initiate the delay interval (in the case of the tandem schedule).

Subject	Condition	Number of sessions	Responses per minute	Session length (minutes) ^a	Obtained delays (seconds)
506	VI	25	58.19	46.94	—
	tandem VI FT 0.5 s	26	51.61	45.43	0.24
	VI	21	53.65	45.75	—
	tandem VI FT 5 s	29	6.78	76.36	3.77
	VI	21	70.51	44.95	—
	tandem VI FT 0.5 s	21	66.86	46.99	0.20
524	VI	20	53.18	45.91	—
	VI	34	33.67	47.07	—
	tandem VI FT 0.5 s	24	38.39	46.84	0.25
	VI	24	50.88	45.06	—
	tandem VI FT 5 s	43	12.96	60.72	3.57
	VI	20	47.18	46.73	—
	tandem VI FT 0.5 s	22	41.34	44.90	0.26
	VI	21	40.84	48.29	—

^a Session length includes time of reinforcer deliveries.

of the full 5.0-s nominal delay, and the remaining delays were distributed evenly across the remaining delay bins.

DISCUSSION

The data from Experiment 2 add generality to the effects of Experiment 1 and those reported by Sizemore and Lattal (1978) and Lattal and Ziegler (1982) by demonstrating that

brief unsignaled delays further increase the size of response units when added to schedules in which high levels of short IRTs already exist. This effect is especially clear in the burst-per-opportunity data. As in the first experiment, these data show that the increases in IRTs shorter than 0.5 s were not simply increases in two-response units separated by intervals of less than 0.5 s. Short IRTs were organized into multiple-IRT bursts.

Fig. 7. Percentage of total IRTs in successive 0.5-s IRT bins, averaged over the last six sessions of each condition. Bin 10 contains all IRTs ≥ 4.5 s. Percentages less than 0.5 have been rounded to zero. Immediate-reinforcement baseline conditions are indicated by a B, and 0.5-s and 5-s delay conditions are indicated by 0.5 s D and 5 s D, respectively. Successive conditions for each subject are depicted from left to right as they occurred sequentially during the experiment.

Table 3

Consecutive IRTs shorter than 0.5 s (burst size) for each bird in each condition of the second experiment. Each entry is the mean for the last six sessions of each condition. All data are from entire sessions. The total number of IRTs shorter than 0.5 s was obtained by multiplying each column entry by the burst size and then summing these products for each condition (row).

Subject	Condition	Consecutive IRTs <0.5 s (burst size)							Total
		1	2	3	4	5	6	7	
506	VI	614	272	88	5	0	0	0	1,442
	tandem VI FT 0.5 s	63	204	216	98	28	7	1	1,700
	VI	393	262	118	25	5	2	0	1,408
	tandem VI FT 5 s	90	25	7	1	0	0	0	165
	VI	361	373	197	57	15	3	1	2,026
	tandem VI FT 0.5 s	28	173	258	185	74	16	3	2,375
524	VI	568	266	66	8	2	0	0	1,340
	VI	447	58	3	0	0	0	0	572
	tandem VI FT 0.5 s	101	214	142	45	10	2	1	1,204
	VI	915	57	7	0	0	0	0	1,050
	tandem VI FT 5 s	162	16	0	0	0	0	0	194
	VI	869	72	13	2	0	0	0	1,060
	tandem VI FT 0.5 s	65	140	184	85	15	4	0	1,336
	VI	707	95	21	9	2	1	0	1,012

GENERAL DISCUSSION

In the first experiment, orderly increases in the frequency of both overall and reinforced short IRTs occurred when brief unsignaled delays preceded reinforcement. This effect was manifested as an increase in the numbers of single and multiple IRTs shorter than 0.5 s from conditions of immediate reinforcement to conditions of briefly delayed reinforcement. The addition of an IRT requirement for reinforcement in the second experiment enhanced the effect. Both the overall and rein-

forced IRT distributions were similar across baseline immediate-reinforcement conditions within each of the two experiments. This finding shows that the effects of unsignaled delays were reversible even though such delays resulted in the reinforcement of predominantly short (if the delay was 0.5 s) or long (if the delay was 5 s) IRTs relative to the those reinforced during baseline.

The IRTs/op data show that the frequency of short IRTs increases disproportionately to IRT increases in other bins with briefly de-

Fig. 8. Bursts per opportunity for bursts comprised of different numbers of IRTs (i.e., burst size), averaged over the last six sessions of each condition. These data were collected over the entire session. Immediate-reinforcement baseline conditions are indicated by a B, and 0.5-s and 5-s delay conditions are indicated by 0.5 s D and 5 s D, respectively. Successive conditions for each subject are depicted from left to right as they occurred sequentially during the experiment.

Fig. 9. Percentage of obtained delays averaged over the last six sessions of each delay condition for each subject in 10 successive delay bins. Each delay bin is 0.05 s in duration for the 0.5-s delay conditions and 0.5 s in duration for the 5-s delay conditions. The values of the nominal delays are indicated above the distributions. The 0.5-s delay condition depicted in the left graphs occurred first.

played unsignaled reinforcement. Although useful in showing this relative increase, the IRTs/op data do not reveal a sufficiently complete picture of the reorganization of behavior engendered by briefly delayed reinforcement. The bursts-per-opportunity data reveal more fully the grouping of IRTs shorter than 0.5 s that develops under briefly delayed reinforcement. In addition, the bursts-per-opportunity data in Figures 5 and 8 indicate that the increases in the frequency of multiple-IRT bursts were not due simply to the increased frequency of short IRTs in the 0.5-s delay conditions. This result supports the earlier suggestions of Lattal and Ziegler (1982) that briefly delayed reinforcement changes the functional unit of be-

havior from single responses preceded by relatively long IRTs to bursts of two or more responses close together.

One may question whether there is in fact a change in the functional response unit, because at least some bursts of responses occur during baseline and the changes during the brief delays never shifted completely to multiple-IRT bursts. Catania (1973) noted that there never is a perfect correlation between the behavior required and produced by the contingency (e.g., reinforcing key pecks also will produce off-key pecks). In a similar way, it is neither possible nor necessary that there be an absolute change from one pattern to another when the contingency changes from immediate

to delayed reinforcement, only that the frequency and reliability of the occurrence of these patterns be demonstrated in a context of many other patterns that are possible.

The mechanism by which the change in the functional unit occurs is suggested by the interaction between the pattern of responding maintained by VI schedules and the brief delay contingency (see Lattal & Ziegler, 1982; Sizemore & Lattal, 1978). Although VI schedules tend to reinforce longer IRTs, short IRTs also are frequent (e.g., Blough & Blough, 1968). On occasion, long IRTs will be followed by short IRTs. With an 0.5-s unsignaled delay added to the VI schedule, the long IRTs that tend to produce the reinforcers (i.e., initiate the delay intervals) occasionally will be followed by short IRTs. On these occasions, the 0.5-s unsignaled delays ensure that these short, intervening IRTs will be reinforced as shown by the data in Figure 3. In a similar way, the 0.5-s delays of Experiment 2 occasionally allowed multiple brief IRTs (bursts) to extend into the delay periods, thereby allowing these bursts to be reinforced. The obtained delay data in Figures 6 and 9 indicate that the effects were obtained even though such response patterns rarely were precisely contiguous with food delivery.

These changes in the local organization of behavior occurred independently of changes in overall response rates. Sizemore and Lattal (1978) found increases in mean overall response rates relative to an immediate-reinforcement condition in each of 2 subjects under 0.5-s nominal unsignaled delays. Rate increases also occurred with 1.0-s nominal delays in 2 of 3 subjects during one of two exposures to the condition. Richards (1981) obtained response-rate increases in 5 of 8 subjects with 0.5-s nominal delays and in 4 of the same 8 subjects with 1.0-s nominal delays, and Lattal and Ziegler (1982) observed large increases in DRL schedules in each of 2 subjects and slight increases in VI schedules for 3 of 4 subjects when 0.5-s nominal delays were imposed. Thus, the present experiments lend further support to the observation that increases in overall response rates as a function of brief (0.5-s) unsignaled delays occur frequently but not invariably.

Several factors may be important in determining the overall response rates that develop under conditions of briefly delayed reinforcement.

First, increases in short IRTs may be accompanied by increases in longer IRTs, thereby averaging out any potential rate increase caused by greater numbers of short IRTs. Second, changes in response-reinforcer temporal contiguity may occur. Thus, even though the number of short IRTs increases, overall response rates may or may not increase as a function of the obtained delay gradient. Although in the present experiment mean delays were only slightly longer than with immediate reinforcement, the delay distributions of Figures 6 and 9 provide a picture differing from that provided by overall means. Many delays were equal or close to the nominal delay value. Other delays were shorter than the nominal delay, but few reinforcers were precisely contiguous with responses.

The baseline immediate-reinforcement schedule also may be important in determining overall response rates under briefly delayed reinforcement. Sizemore and Lattal (1978), Lattal and Ziegler (1982), and Richards (1981) all used VI schedules. However, Sizemore and Lattal, who obtained response-rate increases most consistently, used an arithmetic VI, whereas Lattal and Ziegler, who obtained the effect less consistently, used a constant-probability VI distribution (cf. Catania & Reynolds, 1968). Richards did not specify the type of VI distribution that he used. The consistent response-rate increases obtained with brief unsignaled delays during arithmetic VI schedules may be compared to the magnification of the response-unit-producing effect of such delays during IRT schedules. That is, the pattern of responding generated by arithmetic VI schedules tends to consist of a distinct postreinforcement pause followed by increasingly higher rates of responding as the interreinforcer interval lapses. The pattern may be characterized as a break-and-run pattern. Similarly, a break-and-run pattern, or more precisely a burst-and-pause pattern, characterized responding on the present IRT reinforcement schedules.

The stability criteria in these experiments were specified in terms of overall response rates so that the findings could be compared to the previous experiments involving brief delays of reinforcement. Given the variables described above that might affect overall response rates in concert with briefly delayed reinforcement, it may be appropriate in future experiments

to base stability on more molecular measures of behavior. This suggestion is further strengthened by the contrast between the sensitivity of IRT distributions and overall response rates to briefly delayed reinforcement.

The changes in the frequency of response bursts resulting from brief delays of reinforcement in Experiment 1 were increased in Experiment 2, where bursts of four or five responses were common. For example, the baseline immediate-reinforcement conditions of Experiment 2 often maintained a higher frequency of IRTs shorter than 0.5 s than did the 0.5-s delay conditions of Experiment 1 (cf. Figures 1 and 7). The differences between the results of these two experiments suggest that the baseline immediate-reinforcement schedule is a parameter controlling the effects of other variables in changing response units. Briefly delayed reinforcement imposed on DRL schedules is more likely to yield overall rate increases than such reinforcement imposed following VI baselines. In addition, bursts of responses are more pronounced in DRL schedules (Lattal & Ziegler, 1982).

The present results in conjunction with the preceding data suggest that schedules of IRT reinforcement magnify the response-unit-producing effect of briefly delayed reinforcement. Why should this be? Schedules that differentially reinforce either long or short IRTs maintain a proportionally high frequency of short IRTs (cf. Figures 1 and 7). Thus, in these schedules it seems reasonable to speculate that responses initiating brief delays are likely to be followed quickly by other responses. This in turn would assure a high frequency of bursts just prior to reinforcer delivery and a resultant increase in their overall number, as has been suggested by Sizemore and Lattal (1978) and Lattal and Ziegler (1982).

The comparisons between the 0.5-s and 5.0-s unsignaled delays indicate that the response patterns engendered by the 0.5-s delays are specific to that delay duration and are not a general effect of unsignaled delays per se. Although establishing the range of delay durations from which such effects occur was not the purpose of this experiment, the results do suggest that with longer delays, the development of bursts is less likely. Sizemore and Lattal (1977) reported that when 3-s unsignaled delays were imposed, only 1 of 3 birds devel-

oped a "break and run" pattern . . . in which short bursts of several responses followed a long pause in responding" (p. 122). With this change in pattern, overall response rates were reduced substantially relative to the immediate-reinforcement baseline condition. Overall rate increases have been observed occasionally with 1-s unsignaled nominal delays, but IRT data from these experiments were not reported (Richards, 1981; Sizemore & Lattal, 1978).

The formation of complex functional behavioral units by explicit reinforcement of those patterns is well established. The present results are of particular interest because of the development and persistence of functional behavioral units in the absence of specific requirements for their occurrence. Seemingly subtle changes in contingencies gave rise to large changes in the microstructure of behavior. Behavioral patterning resulting from contingencies has been conceptualized in various ways that include discussions of tempo or rhythmicity in behavior (e.g., Anger, 1956; Blough, 1966; Gilbert, 1958; Shimp, 1975), but one such description seems especially germane here. Himeline (1981) suggested that resonance may be a factor in the organization of behavior. Although the use of brief unsignaled delays of reinforcement may not satisfy his descriptions of a resonant system (which he described in the context of schedule-induced behavior), his analogy between behavior patterns and the physics of sound, especially his notion of harmonics, seems relevant. The schedule of reinforcement may be viewed as a sound generator controlling the characteristic output, in this case responding rather than sound waves. The patterns of responding can be more or less fine-tuned (i.e., consistent or regular) depending on the specific schedule requirements. In such a model the delay may be viewed as analogous to a filter, allowing certain IRTs to occur and thereby increasing the likelihood that they will be reinforced. If a baseline schedule of reinforcement maintains a burst-and-pause pattern of responding, brief unsignaled delays may allow bursts to occur during the delay periods; subsequently, the bursts may be followed by reinforcers. An analysis of the harmonics of the baseline pattern of responding suggests that a larger unsignaled delay also may reinforce bursting. To the extent that the baseline pattern is consistent

or tuned, a larger unsignaled delay may allow the first response of a burst to initiate a delay period. During the subsequent delay one or more additional bursts could occur. Depending on the exact duration of the delay period, the reinforcer may be presented closely in time to a burst. Therefore, delay periods that closely match the duration of a burst-pause episode or a multiple (harmonic) of this duration may differentially reinforce bursting more than unsignaled delays either shorter or longer than the harmonic length. Alternatively, to the extent that the baseline patterns of responding are not synchronized with the delay durations (i.e., there is discord) a cacophony of IRTs might occur during the delay resulting in seemingly random patterns, a behavioral analogy of white noise.

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