

*RESPONDING OF PIGEONS UNDER VARIABLE-INTERVAL
SCHEDULES OF UNSIGNALLED, BRIEFLY SIGNALLED,
AND COMPLETELY SIGNALLED DELAYS TO
REINFORCEMENT*

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In Experiment 1, three pigeons' key pecking was maintained under a variable-interval 60-s schedule of food reinforcement. A 1-s unsignaled nonresetting delay to reinforcement was then added. Rates decreased and stabilized at values below those observed under immediate-reinforcement conditions. A brief stimulus change (key lit red for 0.5 s) was then arranged to follow immediately the peck that began the delay. Response rates quickly returned to baseline levels. Subsequently, rates near baseline levels were maintained with briefly signaled delays of 3 and 9 s. When a 27-s briefly signaled delay was instituted, response rates decreased to low levels. In Experiment 2, four pigeons' responding was first maintained under a multiple variable-interval 60-s (green key) variable-interval 60-s (red key) schedule. Response rates in both components fell to low levels when a 3-s unsignaled delay was added. In the first component delays were then briefly signaled in the same manner as Experiment 1, and in the second component they were signaled with a change in key color that remained until food was delivered. Response rates increased to near baseline levels in both components, and remained near baseline when the delays in both components were lengthened to 9 s. When delays were lengthened to 27 s, response rates fell to low levels in the briefly signaled delay component for three of four pigeons while remaining at or near baseline in the completely signaled delay component. In Experiment 3, low response rates under a 9-s unsignaled delay to reinforcement (tandem variable-interval 60 s fixed-time 9 s) increased when the delay was briefly signaled. The role of the brief stimulus as conditioned reinforcement may be a function of its temporal relation to food, and thus may be related to the eliciting function of the stimulus.

Key words: brief stimulus, conditioned reinforcement, delay of reinforcement, signaled delay of reinforcement, trace autoshaping, trace conditioning, variable-interval schedules, key peck, pigeons

The study of effects of delaying reinforcement of operant behavior has been a focus of empirical and theoretical work for several decades (see reviews by Renner, 1964, and Tarpay & Sawabini, 1974). Most early research concentrated on the effect of delay of reinforcement on acquisition of discriminative control in choice situations (e.g., Grice, 1948; Wolfe, 1934). More recently, interest has been focused on effects of short unsignaled delays to reinforcement on behavior maintained under

schedules of intermittent reinforcement (e.g., Catania & Keller, 1981; Sizemore & Lattal, 1977, 1978; Williams, 1976). Typically, such delays have been found to decrease the rate of pigeons' schedule-maintained pecking. For example, Sizemore and Lattal (1977) added to a variable-interval (VI) 60-s schedule of reinforcement a 3-s unsignaled nonresetting delay (i.e., a delay during which responses had no programmed effects, cf. Catania & Keller, 1981) between pecks that produced food and the actual food presentation. Response rates decreased and stabilized at levels well below those observed under a comparable immediate-reinforcement baseline (VI 63 s). These results may be contrasted with those of Ferster (1953), who found that rates of key pecking under a VI 60-s schedule could be maintained at baseline levels even with a 60-s delay of reinforcement, provided the delay was signaled (by a chamber blackout) and lengthened gradually. More recently, Lattal (1984), employing a

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modified VI schedule (which generated approximately 0.50 to 0.70 reinforcers per minute), found that when 20-s delays were signaled by a blackout rates of key pecking were maintained at values nearer immediate reinforcement baseline levels than when delays were un signaled or when blackouts were not explicitly positively correlated with delays.

The procedures used by Sizemore and Lattal (1977, 1978), Ferster (1953), and Lattal (1984) seem to parallel delays to reinforcement as they occur in natural settings. At times (possibly rarely) delays to reinforcement are un signaled (e.g., an elevator call button with no indicator light). More often, behavior produces some lasting change in environmental circumstances that is correlated with upcoming reinforcement. In many cases, however, reinforced behavior produces momentary changes in environmental conditions (e.g., the ringing of a doorbell) correlated, after a delay, with reinforcement. These situations, with briefly signaled delay of reinforcement, are the focus of the current study.

Although the effects of response-dependent presentations of brief stimuli have not been studied in the context of delayed reinforcement, they have been studied with a variety of other procedures. For example, extensive use of brief stimuli in second-order schedules comprises a major subset of the literature on conditioned reinforcement (e.g., de Lorge, 1971; Stubbs & Cohen, 1972; see Gollub, 1977, and Stubbs, 1971, for reviews). Also, recent experiments have shown that brief ("marking") stimuli presented following the occurrence of either response in a two-alternative situation followed by a delay facilitates acquisition of the reinforced (i.e., "correct") response (Lieberman, Davidson, & Thomas, 1985; Lieberman, McIntosh, & Thomas, 1979; Thomas, Lieberman, McIntosh, & Ronaldson, 1983). Procedurally, however, the experiments reported here more closely resemble the procedures used in trace autoshaping with pigeons (e.g., Kaplan, 1984; Kaplan & Hearst, 1982; Lucas, Deich, & Wasserman, 1981). In these procedures, after a specified, usually variable, interval has elapsed, a keylight (the conditional stimulus, or CS) is illuminated or changes in color for a fixed amount of time, the intertrial conditions are reinstated for a fixed amount of time (the CS-US interval), and then food (the unconditional stimulus, or US) is delivered re-

gardless of what the pigeon is doing. The CS in trace autoshaping procedures usually comes to control stimulus-directed behavior (orientation or key pecking, for example) over a range of temporal and correlative relations between the intertrial interval (ITI), the CS, and the CS-US interval (Gamzu & Williams, 1973; Kaplan, 1984; Lucas et al., 1981). The fact that all the stimuli in trace autoshaping are presented independently of responding is the major difference between it and the current procedure, in which a brief stimulus is response dependent and temporally contiguous with a peck. If the generalizations regarding CSs in trace autoshaping experiments apply in some way to brief stimuli in situations like the present one, the function of these stimuli could be assessed by comparing response rates under un signaled conditions to those obtained when delays are briefly signaled.

In the current study the functions of brief stimuli at the onsets of delays to reinforcement were examined using behavior maintained by variable-interval schedules of reinforcement. In Experiment 1, low response rates observed under 1-s un signaled delay-to-reinforcement conditions were compared to rates obtained when 1-, 3-, 9-, and 27-s delays were signaled by a brief (0.5 s) change in key color. In Experiment 2, brief signals and signals that lasted the entire delay (complete signals) were compared across 3-, 9-, and 27-s delays in the context of a multiple schedule. Experiment 3 compared response rates under a 9-s un signaled delay to those obtained when delays were briefly signaled.

EXPERIMENT 1

METHOD

Subjects

Three experimentally naive, adult male White Carneau pigeons (*Columba livia*) were maintained at approximately 80% of their laboratory free-feeding body weights. They were maintained at these weights with supplemental feeding as necessary after daily sessions or by feeding them at the normal session time on days when sessions were not conducted. Except during experimental sessions, the birds were housed individually in a temperature-controlled colony with a 16:8 hr light/dark cycle.

They had continuous access to water and health grit in their home cages.

Apparatus

Sessions were conducted in a custom-built conditioning chamber for pigeons. The space in which the pigeons were studied measured 30 cm wide by 31 cm long by 31 cm deep. All walls were painted flat black except for the front, which was a brushed aluminum panel equipped with three horizontally aligned, 2-cm diameter response keys (R. Gerbrands Co.) centered 22 cm above a 1-in. hardware-cloth floor. The two side keys remained dark and inoperative throughout the experiment. A static force of 0.14 N or more on the center key (the only one used in this experiment), which was located 15.5 cm from either edge of the front wall, produced a click from a relay and was counted as a response. Two 1.1-W, 28-Vdc lamps, one covered with a green and the other covered with a red translucent cap, could illuminate the response key from behind. Mixed grain was supplied by a solenoid-driven grain feeder through a 6-cm by 5-cm aperture located below the center key. A 1.1-W, 28-Vdc lamp lit the feeder when it was operated, while all other lamps were extinguished. Identical 1.1-W, 28-Vdc lamps, located in the upper corners of the front panel and mounted behind reflectors that prevented direct downward illumination, served as houselights. White noise, which was continuously present in the room where the chamber was located, and noise from a ventilation fan mounted on the chamber ceiling, helped to mask extraneous sounds. A pigeon could be observed through a "fish-eye" peephole on the chamber door and with a video camera aimed through a hole just above the center key. A Digital Equipment Corporation PDP-8[®] minicomputer, located in a separate room and programmed under SUPERSKED[®] software (Snapper & Inglis, 1978), programmed contingencies and collected data. Cumulative records of key pecking during sessions were provided by a Gerbrands cumulative recorder.

Procedure

After exposing the pigeons to the experimental chamber with the houselights on for 45 min, magazine training was begun by placing a pigeon in the chamber with the hopper raised and filled with extra grain. After a pi-

geon had eaten for about 10 s, the hopper was rapidly lowered and reraised. This procedure was repeated, after which the hopper was lowered for increasingly longer times and raised for increasingly shorter times, until the hopper access duration was set at its final value of 4 s. Subsequently, the hopper was raised when the pigeon had moved away from it and was in various locations in the chamber. Magazine training was considered complete when the pigeon consistently went to the hopper and ate immediately after it was elevated. The key peck was then shaped by reinforcing successive approximations to a peck with access to grain. The key was lighted green during this training. After key pecking was established, reinforcement was made gradually more intermittent until a VI 60-s schedule was in effect. The final schedule consisted of 30 intervals determined by the constant-probability method described by Catania and Reynolds (1968, Appendix II). The intervals were selected randomly without replacement by the computer. Sessions lasted until 30 reinforcers were delivered, and were conducted 6 or 7 days per week.

After 65 sessions on the VI 60-s schedule, a 1-s un signaled nonresetting delay (cf. Catania & Keller, 1981) was added. That is, after the scheduled interval timed out, the next response began a 1-s delay, with no change in external stimuli and during which responses were without programmed consequences (except for the feedback relay click that followed all key pecks). At the end of the delay, access to grain was provided independently of any further responding. In the terminology described by Zeiler (1977), the resulting schedule can be labeled tandem (TAND) VI 60 s fixed time (FT) 1 s.

After 45 sessions of exposure to this schedule, the procedure was changed so that a 0.5-s change of stimulation (specifically, the keylight changed to red for 0.5 s and was then reilluminated green) immediately followed the peck that began the 1-s delay. Responses during the delay still had no programmed consequences. This phase lasted 42 sessions. The delay was then lengthened to 3 s, with the 0.5-s brief stimulus still employed, for 38 sessions. A 9-s briefly signaled delay followed for 31 sessions, then a 27-s briefly signaled delay for 64 sessions. The 9-s briefly signaled delay condition was reinstated for 47 sessions, followed

Table 1

Summary of conditions, number of sessions per phase, and reinforcement rates for each subject obtained during the final session of each experimental phase in Experiment 1.

Condition	Sessions	Reinforcers per minute		
		Subjects		
		165	190	844
VI 60 s (no delay)	65	0.99	0.99	0.99
1-s unsignaled delay	46	0.95	0.93	0.91
1-s briefly signaled delay	42	0.97	0.97	0.97
3-s briefly signaled delay	38	0.95	0.95	0.93
9-s briefly signaled delay	31	0.86	0.86	0.87
27-s briefly signaled delay	65	0.56	0.52	0.59
9-s briefly signaled delay	47	0.84	0.86	0.86
VI 60 s (no delay)	10	0.99	0.99	0.99

by the immediate-reinforcement condition (no signal) for a final 10 sessions. A new phase was begun only if inspection of daily plots revealed very little day-to-day variability in response rates for all 3 subjects. If one pigeon's response rates were quite variable or revealed a trend, all 3 pigeons remained in the phase until the variability lessened. The conditions of Experiment 1 are summarized, along with reinforcement rates obtained in the final session of each phase, in Table 1.

Overall response rates, not including time or responses during the delay, were computed daily. Each obtained or actual delay to reinforcement (i.e., the time between food presentation and the last peck to precede it) was collected individually. The numbers of responses during and after the brief stimulus also were collected separately.

RESULTS

Cumulative records for Pigeon 844 (Figure 1) show performance representative of that of all 3 subjects during exposure to immediate reinforcement and unsignaled and briefly signaled delays to reinforcement. A steady rate of key pecking typical of that engendered by VI schedules developed under the VI schedule (0 SEC). Decreases in response rates and more erratic patterns of pecking were observed under the unsignaled 1-s delay (1 SEC:NS) and

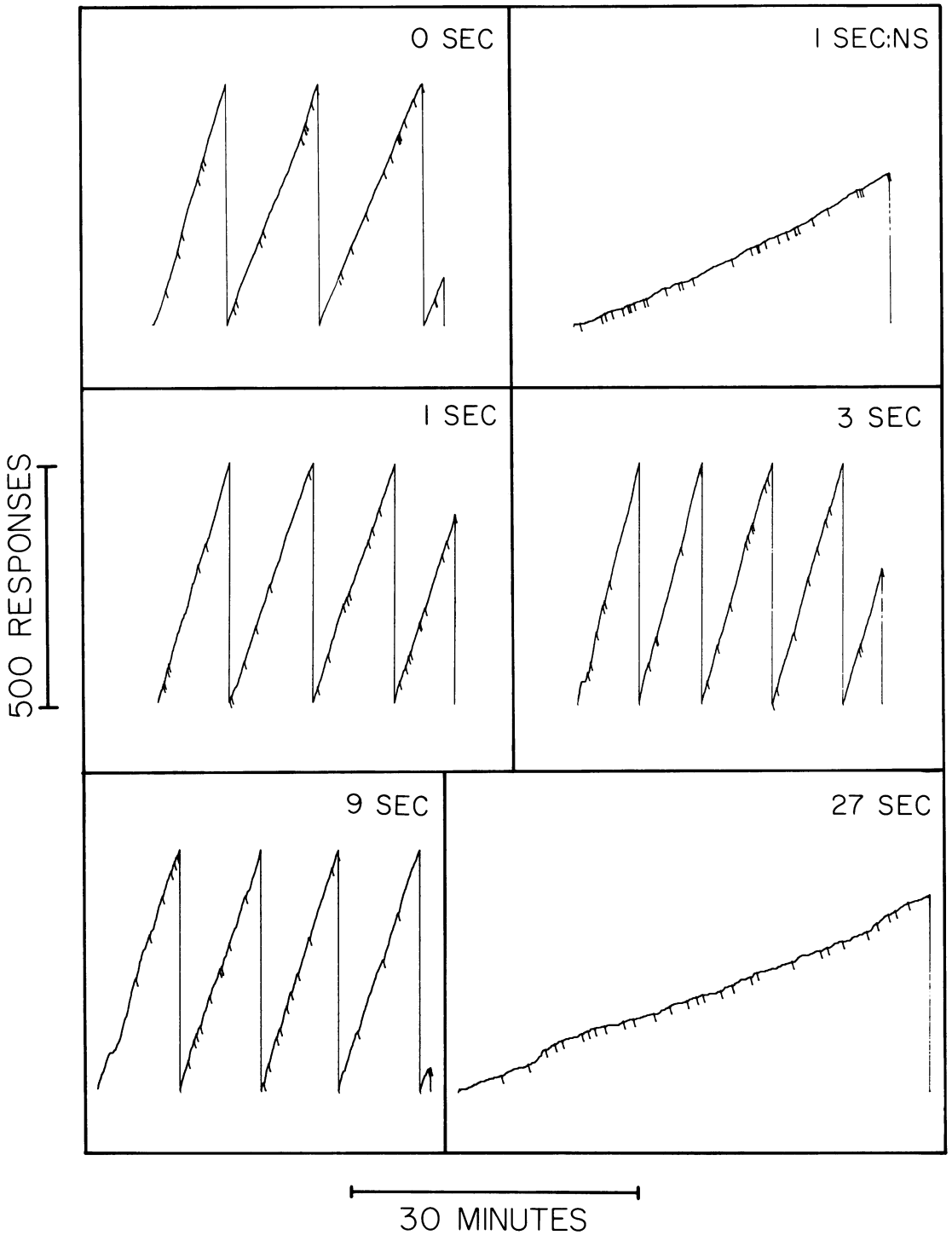
the 27-s briefly signaled delay. Response rates under conditions with briefly signaled delays of 1, 3, and 9 s were slightly higher for this pigeon than those observed under immediate-reinforcement conditions. During the briefly signaled 9-s delay phase that followed exposure to the 27-s briefly signaled delay, cumulative records were essentially identical to those obtained during the initial 9-s delay phase (except that key-peck rates were slightly higher during the second exposure).

Figure 2 shows responses per minute for all 3 subjects during the last 10 sessions of the initial VI 60-s baseline, the first 10 sessions of the final VI 60-s phase, and the first and last 10 sessions of each delay phase. Response rates declined systematically during the 1-s unsignaled delay phase to well below immediate-reinforcement baseline rates. Response rates increased when the brief signal accompanied the beginning of the delay interval. For Pigeon 165, near-baseline rates were maintained at 3-s and 9-s delays. For Pigeons 190 and 844, response rates were actually somewhat higher under briefly signaled delay conditions than those observed under baseline conditions, with the highest response rates observed under the second exposure to the 9-s briefly signaled delay condition. When the delay was lengthened to 27 s, however, response rates fell gradually, in approximately 30 to 40 sessions, to a rate of fewer than 10 pecks per minute for each pigeon. Rates increased upon return to the 9-s delay, with two pigeons' (190 and 844) rates increasing in the first 10 sessions and the third pigeon's (165) rates increasing more slowly to near the immediate-reinforcement baseline.

Reinforcers per minute, obtained from the last session of each phase for each pigeon, are shown in Table 1. Reinforcement frequencies decreased as the programmed delay was lengthened, with the lowest frequencies obtained during the 27-s delay phase.

Frequency distributions of obtained delays to reinforcement are shown in Figure 3 for all three pigeons, based on data from the last session of exposure to the 1-s unsignaled delay and the last session with the briefly signaled 1-s delay. These distributions are represen-

Fig. 1. Cumulative response records of performance by Pigeon 844 in Experiment 1 under immediate reinforcement (0 SEC), 1-s unsignaled delay to reinforcement (1 SEC:NS), and 1-, 3-, 9-, and 27-s briefly signaled delays to



reinforcement. *Y* axes, cumulative key pecks; *X* axes, time. Short diagonal marks indicate food presentations. The cumulative recorder operated during delays. Performance is characteristic of all 3 subjects. Key-peck rates in the sessions from which these records were selected were near the mean of the final five sessions of each phase. The performances under the reexposures to the 9-s briefly signaled delay and the immediate-reinforcement conditions differed little from the performance in the initial exposures and thus were omitted.

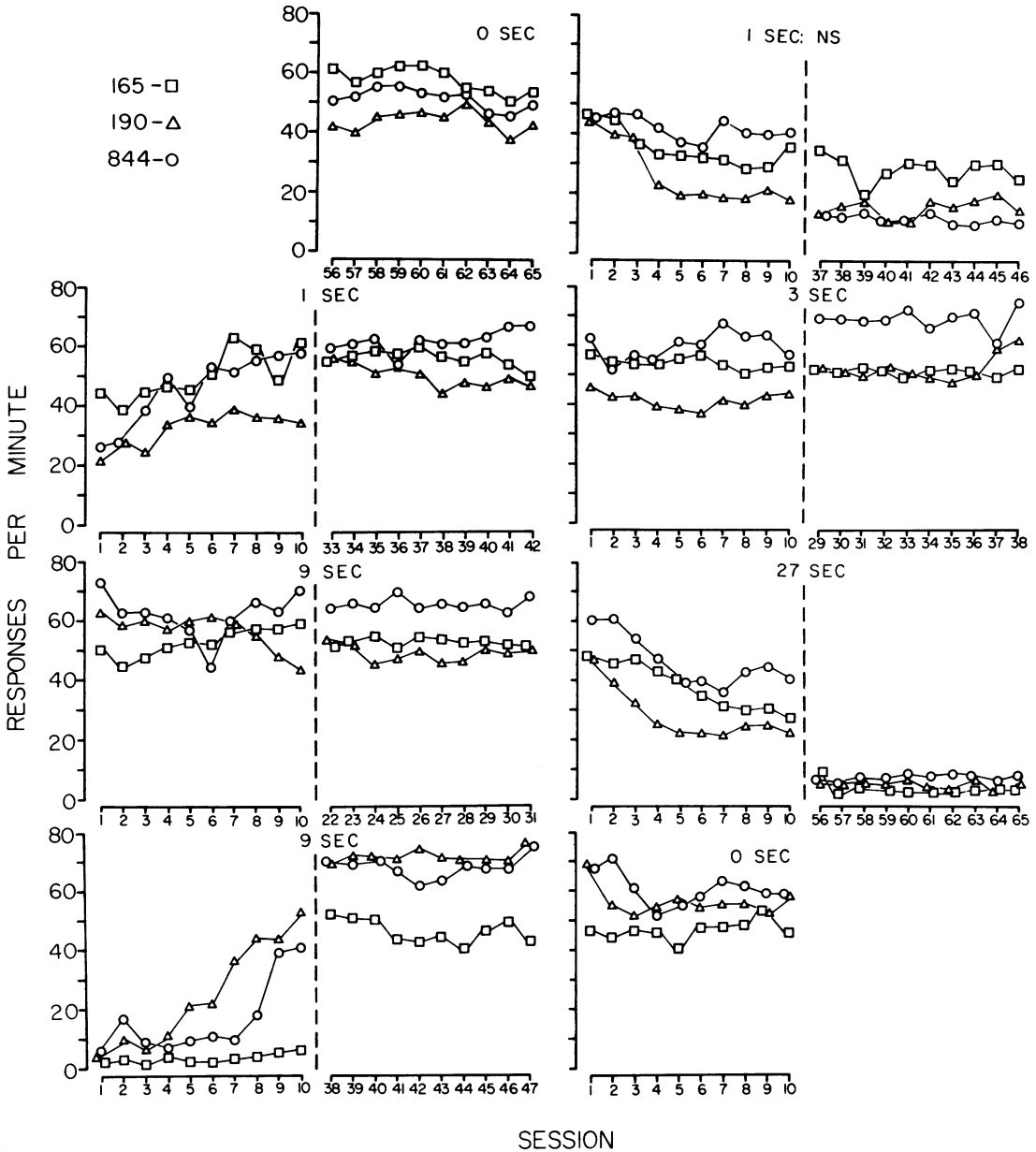


Fig. 2. Rates of key pecking, exclusive of time during delays, for all 3 subjects in Experiment 1 for the last 10 sessions of the first immediate-reinforcement condition (top left graph), the 10 sessions of the final immediate-reinforcement condition (bottom right graph), and the first and last 10 sessions of the 1-s un signaled delay condition (1 SEC:NS), and 1-, 3-, 9-, and 27-s briefly signaled delay conditions (graphs in second and third rows), and the reexposure to the 9-s briefly signaled delay condition (bottom left graph). Sessions were numbered beginning at one in each phase. Dashed vertical lines separate data from the first 10 and last 10 sessions of a phase. Squares show data for Pigeon 165, triangles those for Pigeon 190, and circles those for Pigeon 844.

tative of the distributions obtained over the final sessions of these phases. The obtained delay distributions for the un signaled delay (left column) reveal that, for all 3 subjects, the modal obtained delay was 1 s. Some between-

subject variability in the distributions of the remaining (<1.0 s) delays is present, ranging from a second mode at 0.1 to 0.2 s for Pigeon 165 to a single 0.9-s delay for Pigeon 844. Overall, obtained delays became shorter after

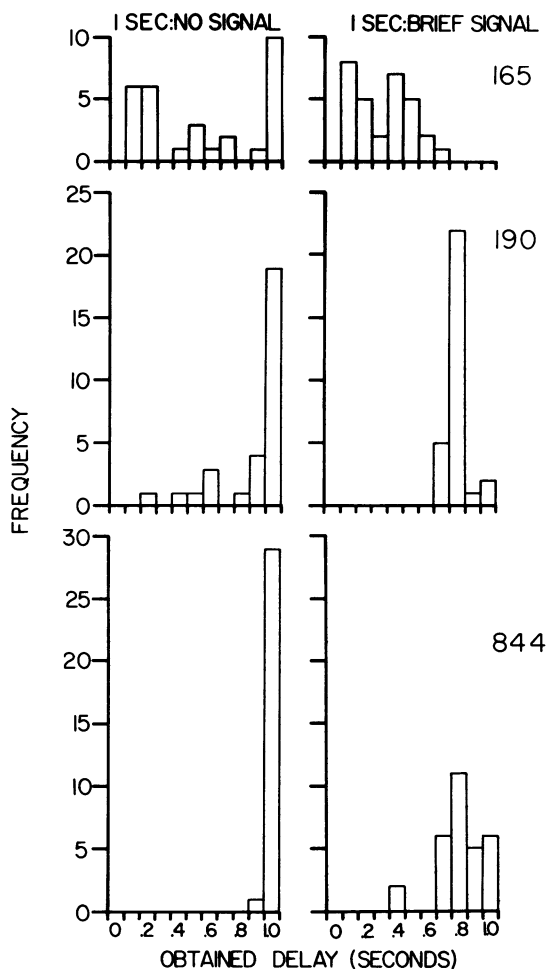


Fig. 3. Frequency distributions of obtained or actual delays to reinforcement for each of the 3 subjects in Experiment 1 during the last session of the 1-s unsignaled delay condition (left panels) and the 1-s briefly signaled delay condition (right panels). Distributions are representative of those collected in the last five sessions of these conditions. Obtained delays are resolved to 0.1 s.

the 0.5-s brief signal was added. For Pigeons 190 and 844, the mode at 1.0 s disappeared; obtained delays indicate that the final responses during the programmed delay occurred when the signal was lit (i.e., with delays between 0.5 and 1.0 s). Most obtained delays for Pigeon 165 were less than 0.5 s, indicating that this subject usually responded throughout the delay.

Figure 4 provides a comparison of the obtained-delay distributions for the last session of the initial exposure to the briefly signaled 9-s delay phase (left panel) and the second exposure to this condition (right panel). For

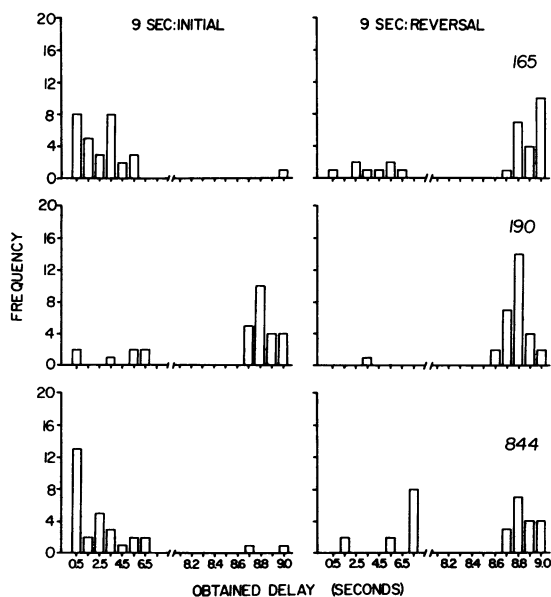


Fig. 4. Frequency distributions of obtained or actual delays to reinforcement for each of the 3 subjects in Experiment 1 during the last session of the initial 9-s briefly signaled delay condition (left panels) and the last session of reexposure to the 9-s briefly signaled delay (right panels). Distributions are representative of those collected in the last five sessions of these conditions. Obtained delays to reinforcement between 8.1 and 9.0 s are resolved to 0.1 s; the total frequency of obtained delays in the 8.1 to 9.0-s bin may be obtained by summing across the 0.1-s bins. Delays less than 8.0 s are resolved to 1 s.

greater resolution, the first second of the delay (8.1 to 9.0 s) is represented again in 0.1-s units to the right of each distribution. For Pigeons 165 and 844, obtained delays during the first exposure were distributed across the entire 9 s, with several delays of less than 5 s. During the second exposure to the 9-s briefly signaled delay condition the majority of obtained delays were 8.5 to 9.0 s long, which means that there were few responses during the programmed delay. The same type of change was observed for Pigeon 190. For all 3 subjects, then, distributions of obtained delays shifted from the initial exposure to the 9-s briefly signaled delay phase to the reversal to this condition, with more 8.6-s to 9-s obtained delays, which means that fewer responses occurred after the brief signal.

A measure of pecks to the brief signal may help assess whether the rate-increasing effect of the brief signal in the present experiment can be related to the eliciting effects of the CS in trace conditioning arrangements. Figure 5

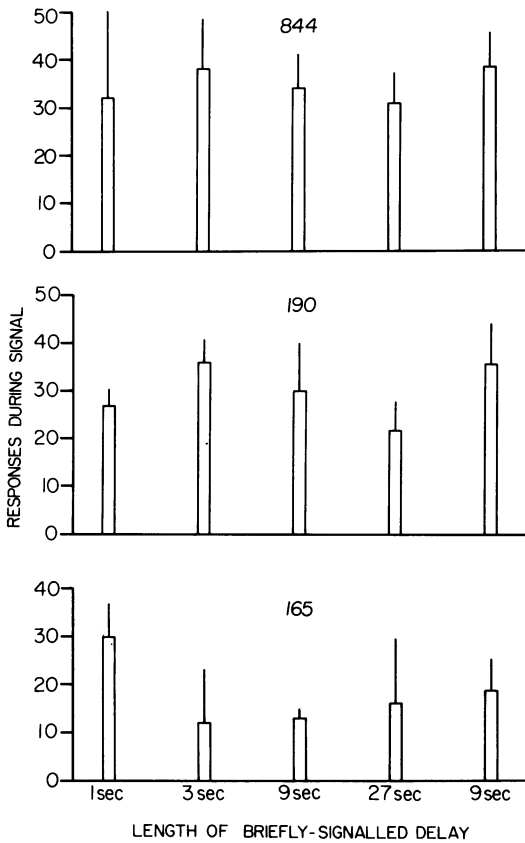


Fig. 5. Mean number of responses (computed over the last five sessions) during the 0.5-s brief signal for each of the 3 subjects in Experiment 1 during the 1-, 3-, 9-, and 27-s delay conditions, and reexposure to the 9-s briefly signaled delay condition. Lines extending above the bars depict the upper halves of 95% confidence intervals.

depicts the mean number of responses during the 0.5-s brief signal during a session (means of last five sessions of a phase; pecks that begin the delay are not counted here). For Pigeons 190 and 844 a slight decreasing trend from the 3-s to the 27-s delay is evident, with an increase upon return to the 9-s delay. For Pigeon 165, however, pecks during the brief signal were highest during the 1-s briefly signaled delay, decreased during the 3-s delay, and increased steadily throughout the rest of the experiment.

DISCUSSION

For each of the 3 pigeons, when a 1-s un-signaled delay to reinforcement was imposed, rates of key pecking decreased relative to those observed under immediate-reinforcement conditions. Rates increased when a 0.5-s change

in key color immediately followed the peck that began the delay, and response rates remained near baseline levels or higher at briefly signaled 3- and 9-s delays. When a 27-s briefly signaled delay was imposed, rates of pecking declined to low levels. Upon return to the 9-s briefly signaled delay condition, rates increased to higher-than-baseline levels in 2 of 3 subjects and to near-baseline levels for the third.

The distributions of obtained delays (Figures 3 and 4) help to reveal whether the rate-increasing and rate-maintaining effect of the brief signal can be attributed to changes in the actual peck-food intervals. Figure 3 shows that, overall, obtained delays to reinforcement were shorter under the 1-s briefly signaled delay condition (right panels) than under the 1-s un-signaled delay condition. This suggests that the brief signal's rate-increasing effect may have resulted from its effect on obtained delays; the brief stimulus produced decreases in the average obtained response-food interval, which in turn resulted in increases in response rates. Figure 3, then, does not provide evidence that can effectively rule out the possibility that rates increased because of accidental peck-food contiguities. Figure 4 shows that distributions of obtained delays differed within subjects across 9-s briefly signaled delay conditions. For Pigeons 165 and 844 the modal obtained delay observed during the second 9-s delay condition (right panels) was between 8.5 and 9.0 s; during the first exposure to the 9-s delay condition obtained delays were distributed across the entire 9-s delay. The distributions from the second exposure to the 9-s delay condition suggest that key pecking was not maintained by accidental peck-food contiguities, because pecks rarely occurred after the brief signal was withdrawn. The possibility remains, however, that response rates were maintained at high levels in the initial 9-s delay condition because of the several relatively short obtained delays. It is possible that during exposure to the 27-s briefly signaled delay condition, the function of the brief stimulus changed; the signal may have acquired S-delta properties by association with a relatively long period of nonreinforcement that carried over to the second 9-s delay condition, thus decreasing the likelihood of pecking after the brief signal. For now it may be concluded that a specific distribution of obtained delays to reinforcement does not seem

to be required for the brief signal to maintain baseline or higher-than-baseline response rates, although in some cases short peck-food intervals may play a role.

Commonly, the effectiveness of trace auto-shaping procedures for conditioning is evaluated by observing behavior during the CS. Figure 5 provides such an observation, and reveals that pecking during the brief signal was not a reliable function of programmed delay length across subjects. Although for Pigeons 190 and 844 decreases in the number of responses occurring during the brief stimulus are evident as programmed delays increase (which should occur as the CS-US interval is increased under trace auto-shaping procedures), data for Pigeon 165 indicate a slight increase in the number of responses during the brief signal across experimental conditions. Data in Figure 5 are difficult to interpret, because changes in the number of pecks during the brief signal could reflect either changes in the peck-eliciting function of the brief signal or changes in the overall distributions of interresponse times (IRTs) regardless of the presence or absence of the signal. If patterns of responding included more or fewer "bursts" of different lengths under different delay conditions, Figure 5 may reflect this change alone. So although Figure 5 does not strongly support a trace-conditioning interpretation of the results of Experiment 1, this may be because it is a poor indicator of control by presumed Pavlovian relations.

The decreases in response rates observed under the 27-s briefly signaled delay condition may have resulted, in part, from the substantial decreases in rates of food presentation obtained under that condition (see Table 1). Lattal (1987), in a discussion of important control procedures in the study of delayed reinforcement, noted that reinforcement frequency must be controlled across delay conditions to prevent its functioning as a confounding variable. In the present Experiment 2, different delay-signal conditions were arranged in separate components of a multiple schedule, while reinforcement frequencies were held constant across components. Differences in response rates observed across components, then, can be attributed more confidently to differences in delay-signal conditions rather than differences in reinforcement frequency.

Other questions remain regarding the effects demonstrated in Experiment 1. For ex-

ample, although response rates increased relative to those observed under a 1-s unsignaled delay to reinforcement when the delay was briefly signaled, rates of key pecking were only maintained at 3- and 9-s delays. It could be that the rate-maintaining function of the brief signal at these delays depended on the history of briefly signaled delayed reinforcement at a 1-s delay, that is, that the effectiveness of the brief signal at the longer delays was "shaped" gradually, possibly by arranging relatively short obtained delays. Also, it is not known whether briefly signaling delays to reinforcement differs from signaling delays with a stimulus that remains in place throughout the delay (i.e., a conventional or completely signaled delay). Experiment 2 was designed to provide answers to these questions.

EXPERIMENT 2

METHOD

Subjects

Four experimentally naive, adult male White Carneau pigeons (*Columba livia*) were used. Conditions of deprivation, care, and maintenance were the same as in Experiment 1.

Apparatus and Procedure

The apparatus was the same as that used in Experiment 1. Preliminary procedures were the same as those employed in Experiment 1. After shaping pecks at a key with a red key-light, each peck produced food on a fixed-ratio (FR) 1 schedule during two sessions of 50 hopper presentations each. During the first of these sessions the key was lighted red; during the second the key was lighted green (Pigeon 4582 received only one session of FR 1 with 25 reinforcers presented for pecks on the red key and 25 reinforcers presented for pecks on the green key). During the next session the response requirement was increased gradually to FR 15 in the presence of either red or green keys, which alternated after each reinforcer. The baseline schedule was then introduced. It was a multiple schedule in which a VI 1-min schedule in the presence of a green key (Component 1) alternated with a VI 1-min schedule in the presence of a red key (Component 2). Both schedules consisted of 30 intervals determined by Catania and Reynolds' (1968, Ap-

Table 2

Summary of conditions, number of sessions per phase, and reinforcement rates for each subject obtained in briefly signaled delay and completely signaled delay components during the 10th and the final session of each phase of Experiment 2. Delays between the peck that produced food and presentation of food were added to a MULT VI 60-s VI 60-s schedule.

Delay	Signal conditions	Subject	Sessions	Reinforcers per minute			
				10th session		Last session	
				BS ^a	CS ^b	BS	CS
0 s	none	269	84			1.0	1.0
		422	78			0.90	0.93
		407	78			1.0	0.90
		4582	78			0.97	1.0
3 s	unsigned	269	37	0.80	0.85	0.85	0.88
		422	39	0.86	0.79	0.55	0.70
		407	38	0.80	0.88	0.76	0.82
		4582	58	0.96	0.94	0.91	0.94
3 s	briefly signaled	269	35	0.94	0.80	0.91	0.94
		422	43	0.86	0.79	0.55	0.70
		407	39	0.94	0.96	0.82	0.91
		4582	53	0.94	0.88	0.94	0.85
9 s	briefly signaled	269	59	0.86	0.81	0.87	0.83
		422	43	0.81	0.88	0.84	0.84
		407	39	0.81	0.86	0.86	0.76
		4582	53	0.84	0.88	0.84	0.88
27 s	briefly signaled	269	50	0.69	0.68	0.42	0.68
		422	49	0.69	0.70	0.66	0.67
		407	38	0.57	0.65	0.49	0.67
		4582	89	0.64	0.67	0.67	0.65
9 s	briefly signaled	269	20	0.84	0.88	0.86	0.86
		422	20	0.87	0.89	0.87	0.79
		407	15	0.81	0.78	0.78	0.78
		4582	20	0.76	0.76	0.84	0.83

^a Briefly signaled delay component.

^b Completely signaled delay component.

pendix II) constant-probability method. The intervals were selected randomly without replacement by the computer. Components ended after variable lengths of time had elapsed (6, 10, or 14 min; $M = 10$ min), excluding reinforcement and delay periods. Consequently, components could not end during a delay. If a component ended during an interval, the time elapsed in that interval counted toward completion of the interval when the component reappeared (unless it was the last component of the session). Component durations were selected randomly without replacement by the computer, and each duration occurred once per session. Component 1 (green key) always began the session, and the session ended after both components had been presented three times. Components were separated by 1-min blackouts (all lights in the chamber extin-

guished). Experimental sessions were conducted 6 or 7 days per week.

After rates of responding had become stable on this schedule, a 3-s unsigned nonresetting delay was inserted between pecks that produced the reinforcer and reinforcer presentation in both components. Circumstances during the delay were the same as those that prevailed in Experiment 1. In the terminology described by Zeiler (1977), the resulting schedule can be labeled a multiple (MULT) tandem VI 60 s FT 3 s (Component 1) tandem VI 60 s FT 3 s (Component 2).

After response rates had become stable under this schedule, the schedule was changed so that in Component 1 a 0.5-s change in key color immediately followed the peck that began the 3-s delay (brief signal), and in Component 2 a change in key color that lasted the entire

delay immediately followed the peck that began the delay (complete signal). For Pigeons 269 and 422 the brief signal was a white key and the complete signal was a blue key; for Pigeons 407 and 4582 the brief- and complete-signal colors were reversed. In Component 1, following the 0.5-s brief signal the green key was reilluminated for the remainder of the delay. Responses during the delay still had no programmed consequences. When rates of pecking stabilized the delay in both components was lengthened to 9 s, again briefly signaled in Component 1 and completely signaled in Component 2. In the next phase the delay was lengthened to 27 s in both components, with signals arranged as before. After stable response rates were observed at this delay, the 9-s delay condition was reinstated, followed finally by the immediate-reinforcement condition (no signals) for 15 to 20 sessions. The order of sessions and number of sessions per phase, as well as rates of food presentation obtained in the 10th and in the last session of each phase, are shown in Table 2. A new phase was begun only if inspection of daily plots revealed very little day-to-day variability in response rates with no upward or downward trends.

Overall response rates, not including time or responses during the delay, were computed daily. Each obtained or actual delay to reinforcement was collected individually. The numbers of responses during and after the brief signal and during the complete signal also were collected separately.

RESULTS

The cumulative records in Figure 6 show performance of Pigeon 269, which was representative of that of all 4 subjects under immediate reinforcement and unsignaled, briefly, and completely signaled delays to reinforcement. A steady rate of pecking typical of that engendered by VI schedules developed under the baseline MULT VI 60-s VI 60-s schedule (labeled "0 SEC" in the figure). Response rates

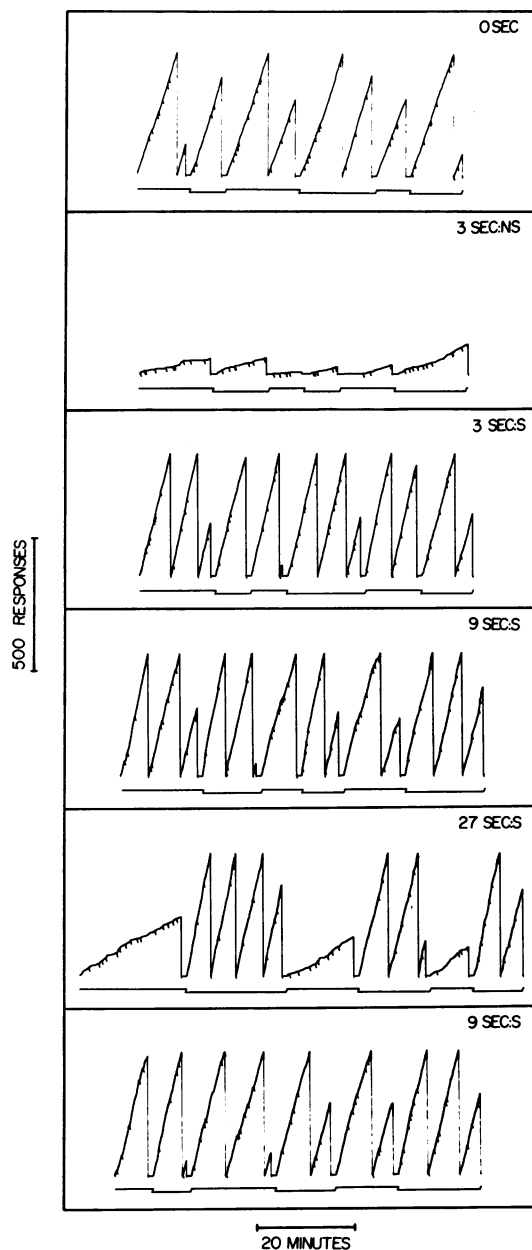


Fig. 6. Cumulative response records showing performances of Pigeon 269 in Experiment 2 under MULT VI 60 s VI 60 s (immediate reinforcement; 0 SEC), 3-s unsignaled delays to reinforcement in both components (3 SEC:NS), and 3-, 9-, and 27-s briefly signaled and completely signaled delays to reinforcement. Y axes, cumu-

lative key pecks; X axes, time. Short diagonal marks indicate food presentations. Components with briefly signaled delays were in operation when the lower (event) pen was raised; components with completely signaled delays were in operation when the event pen was deflected downward. The cumulative recorder operated during delays and the motor operated during the 60-s blackout that separated components. Performances are similar to those of Subjects 422 and 407, but not to that of 4582 during the component with briefly signaled delays at the end of the 27-s delay condition (27 SEC:S). Key-peck rates in the sessions from which these records were selected were near the means for the final five sessions of each phase.

decreased and temporal patterns of pecking became more erratic when the 3-s un signaled delay was added (3 SEC:NS). Response patterns approximating those observed under immediate-reinforcement conditions and response rates slightly higher than baseline levels were observed under briefly and completely signaled delays of 3 and 9 s (3 SEC:S, 9 SEC:S). Although rates of pecking remained near baseline levels with a 27-s delay during the completely signaled delay component, they decreased and temporal patterns of responding grew more erratic in the component with briefly signaled delays (27 SEC:S). Upon return to the 9-s delay, rates and patterns recovered in the component with briefly signaled delays and remained near baseline levels in the component with completely signaled delays.

Figure 7 shows responses per minute for the last 10 sessions of the initial MULT VI 60-s VI 60-s baseline and the first and last 10 sessions of each delay phase for all 4 subjects. During the first 10 sessions of the 3-s un signaled delay phase, response rates declined in both components and stabilized at rates well below immediate-reinforcement baseline levels (ranging from 0 to 10 responses per minute for Pigeon 269 to about 20 responses per minute for Pigeon 4582). Response rates began to recover within the first 10 sessions when the delay interval was signaled, whether briefly or completely, and became stable at higher-than-baseline levels for Pigeons 422 and 269, at slightly lower-than-baseline levels for Pigeon 407, and at near-baseline levels for Pigeon 4582. No systematic differences in response rates between briefly and completely signaled delay components were observed at this delay, except for Pigeon 4582, for which rates in the briefly signaled delay component were slightly higher than those observed in the completely signaled delay component.

A disruption in performance during the briefly signaled delay component accompanied the first 10 sessions of the initial 9-s delay phase for Pigeons 422 and 4582, but rates became stable at or above baseline levels in the briefly signaled delay component for all four pigeons. Rates in the component with completely signaled delays for Pigeon 4582 became stable 20 to 25 responses per minute lower than rates in the component with briefly signaled delays during the 9-s delay phase. When the delay was lengthened to 27 s, response rates

in the briefly signaled delay component began to fall gradually in all four pigeons within the first 10 sessions whereas rates in the completely signaled delay component were either unaffected or decreased (for Pigeon 422). For Pigeons 422, 269, and 407, response rates in the briefly signaled delay component became stable at low levels while rates in the completely signaled delay component remained high. For Pigeon 4582, however, briefly signaled delay component rates decreased and became stable at levels equal to completely signaled delay component response rates, which did not change. Upon return to the 9-s delay, response rates in the briefly signaled delay component increased for all four pigeons to levels near those observed in the initial 9-s delay phase.

As in Experiment 1, decreases in reinforcement frequencies were observed for each subject as the programmed delay was lengthened. Table 2 shows reinforcement frequencies (reinforcers per minute) obtained during the 10th and during the final session of each delay phase. Across 3- and 9-s delay conditions, reinforcement rates in the two components did not differ systematically across subjects. Reinforcement rates obtained for Pigeons 269, 422, and 4582 during the 10th session of the 27-s delay condition were nearly equal in the two components. For Pigeons 269 and 407, response rates in the briefly signaled delay component eventually decreased enough during this phase to reduce reinforcement frequency relative to that obtained in the completely signaled delay component. Reinforcement rates for Pigeons 422 and 4582 during the final session of the 27-s delay phase were nearly equal between components.

Median obtained delays from the last sessions of the 3-s un signaled delay condition and the briefly and completely signaled 3-, 9-, and 27-s delay conditions are shown in Figure 8. For Pigeons 269, 422, and 407, obtained delays during the un signaled delay condition were near the programmed maximum (3 s), and for all subjects there were no appreciable differences in obtained delays between the two components during this phase. For Pigeons 422 and 269 (upper panels), obtained delays in both components became very short when the 3-s delays were signaled, whereas for Pigeons 407 and 4582 (lower panels), obtained delays did not change when these delays were sig-

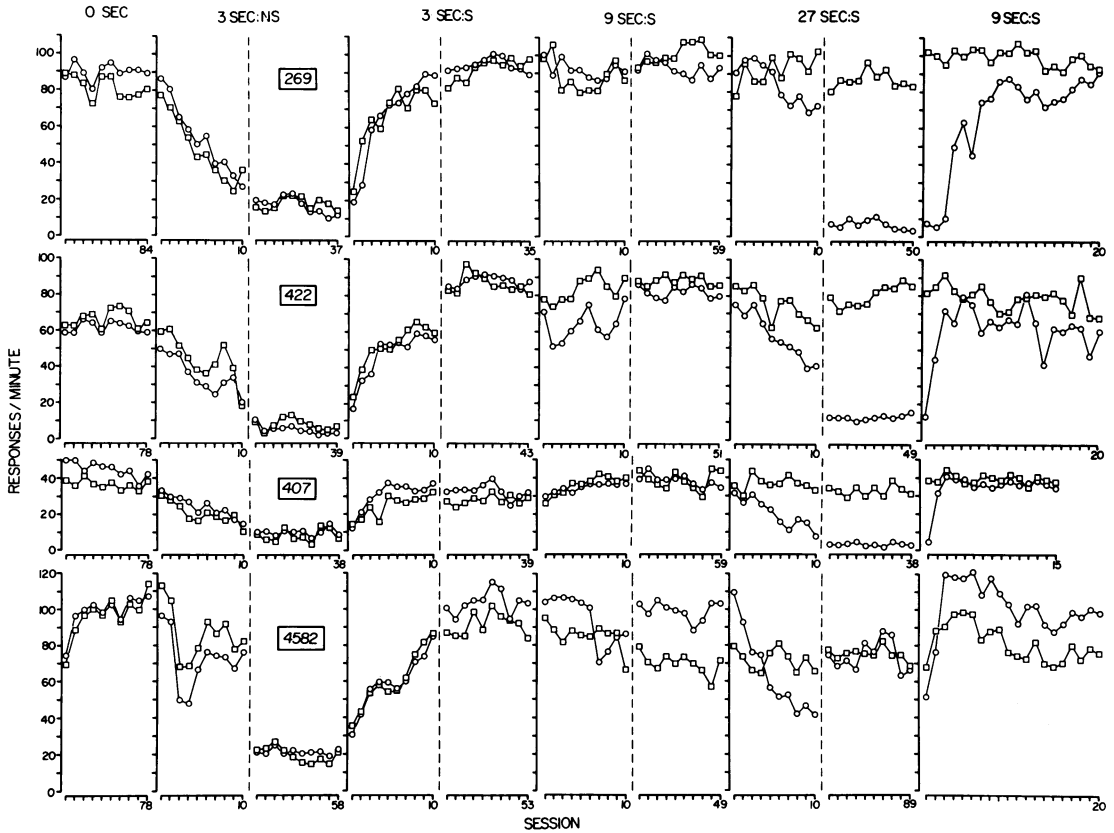


Fig. 7. Rates of key pecking, exclusive of time during delays, for all 4 subjects in Experiment 2 during the last 10 sessions of the first immediate-reinforcement condition (far left, 0 SEC), the first and last 10 sessions of the 3-s unsignaled delay condition (3 SEC:NS), the 3-, 9-, and 27-s briefly and completely signaled delay conditions, and all sessions of reexposure to the 9-s briefly and completely signaled delay condition (far right, 9 SEC:S). Sessions were numbered beginning at one in each phase. Dashed vertical lines separate data from the first 10 and last 10 sessions of a phase. Rates of pecking in the component with briefly signaled delays are depicted by open circles; rates of pecking in the component with completely signaled delays are depicted by open squares.

naled. During the 27-s delay condition, Pigeons 422 and 269 produced very short median obtained delays in the completely signaled delay component, but obtained delays for Pigeons 407 and 4582 in the same component during the 27-s delay condition were near the programmed delay (27 s). Median obtained delays during the other delay conditions differed less, both between components and across subjects. Unlike actual delays obtained during the second 9-s delay condition of Experiment 1, obtained delays during the second exposure to the 9-s delay condition of the present experiment were nearly equal to those obtained in the initial exposure to this condition.

Another measure of key pecking across delay phases is depicted in Figure 9. This figure shows the mean number of pecks per brief

signal presentation across all briefly signaled delay values (left panel) and the mean rate of pecking (pecks per second) observed during the complete signal across all delay values (right panel) for the last five sessions of each phase. Pecks during the brief signal were essentially an increasing function of the programmed delay for Pigeons 422, 269, and 4582, but for Pigeon 407 pecks during the brief signal decreased as the delay was increased. Rates of pecking during the complete signal decreased across delays for Pigeon 422 (open squares), but for Pigeons 269, 4582, and 407 mean rates of pecking during the complete signal were highest during the initial exposure to the 9-s delay condition and lowest during the 27-s delay phase. Pigeons 407 and 4582 (upright and inverted triangles) rarely pecked the key

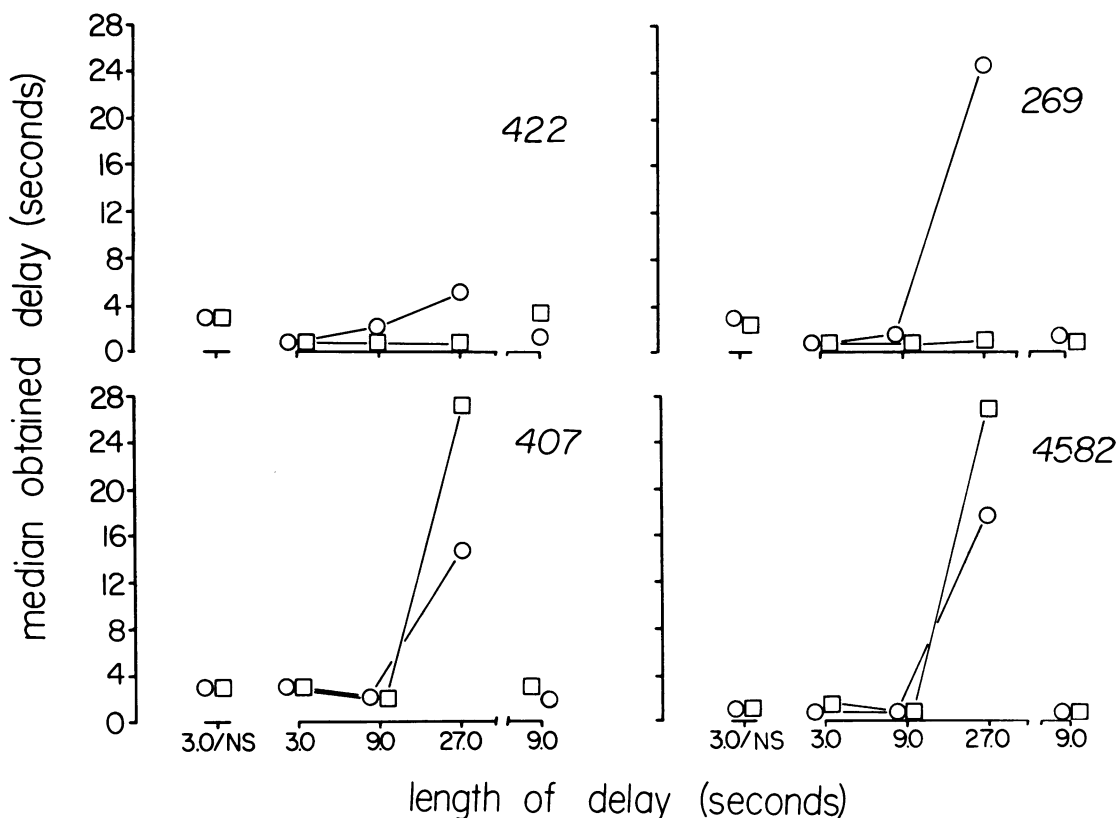


Fig. 8. Median obtained or actual delays to reinforcement for each subject in Experiment 2 under unsigned 3-s delays to reinforcement (3.0/NS) and briefly signaled (open squares) and completely signaled (open circles) 3-, 9-, and 27-s delay conditions. Medians were computed from the last session of each phase. Open circles depict median obtained delays in the component with briefly signaled delays, and open squares depict median obtained delays in the component with completely signaled delays.

during the 27-s completely signaled delay (as also indicated by obtained delays for these pigeons during this phase; see Figure 8). For Pigeons 269, 407, and 4582, the mean rates of pecking during the complete signal were lower on the second exposure to the 9-s delay phase than on the first exposure to this phase.

DISCUSSION

Brief and complete delay signals presented contiguously with pecks that began delays to reinforcement produced increases in rates of responding relative to low rates observed under a 3-s unsigned delay. Nearly equal rates were maintained in briefly and completely signaled delay components during a 9-s delay phase. Rates of pecking remained high during the component in which delays were completely signaled when the delay was lengthened to 27 s, but decreased to low levels in 3 of 4 subjects in the briefly signaled delay component.

High rates and steady patterns of pecking were recovered in the briefly signaled delay component when a 9-s delay was reimposed.

The results of this experiment showed that low response rates observed under a longer unsigned delay (3 s) than that imposed in Experiment 1 (1 s) increased when the delay was briefly signaled. Maintenance of relatively high rates of key pecking during the 3-s briefly signaled delay phase in Experiment 1, then, may not have required experience with briefly signaled delays at a shorter delay value. Experiment 2 also showed that when delays were completely signaled response rates were maintained at high levels at longer programmed delays (27 s) than when delays were signaled briefly. One exception is Pigeon 4582, whose response rates were nearly identical across components during the 27-s delay phase. It is not clear why results from this pigeon differed from those of the other subjects.

In Experiment 1, the reduction in rates of

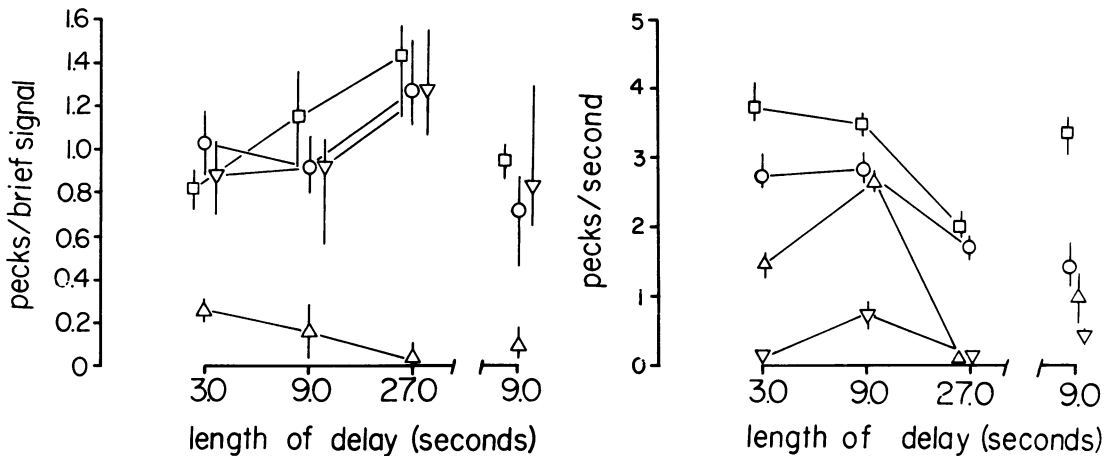


Fig. 9. The left panel shows responses per brief signal for each subject in Experiment 2 during briefly signaled delays of 3, 9, and 27 s, and during the second 9-s briefly signaled delay condition. The right panel shows response rates during the complete signal in the component with completely signaled 3-, 9-, and 27-s delays, and during the second 9-s completely signaled delay condition. Squares, Pigeon 269. Circles, Pigeon 422. Inverted triangles, Pigeon 4582. Triangles, Pigeon 407. Vertical lines indicate ranges.

pecking observed during the 27-s delay phase may have been related to the nearly one-third decrease in reinforcement frequency (see Table 1). In Experiment 2, however, large decreases in response rates in the component with briefly signaled delays (ranging from 20 pecks per minute for Pigeon 269 to 60 pecks per minute for Pigeon 4582) occurred during the first 10 sessions of the 27-s delay phase, whereas for three pigeons, no decreases in response rates in the component with completely signaled delays occurred. Reinforcement frequencies for three of four pigeons during the 10th session of the phase, however, were equal under both components (see Table 2). In addition, response rates in the final session of the 27-s delay phase were substantially lower in the briefly signaled delay component than those observed in the completely signaled delay component for 3 of 4 subjects, but reinforcement frequencies for Pigeon 422 were nearly identical. It is certainly possible that changes in reinforcement rate as large as those observed in these experiments contributed to reductions in rates of pecking, but the observations above suggest that change in reinforcement frequency was not the only variable operating.

Median obtained delays (Figure 8) revealed considerable variability across subjects. In particular, the obtained delays under unsignaled versus the signaled 3-s delay conditions reveal no changes for Pigeons 407 and 4582 and a shift to very short obtained delays in Pigeons

422 and 269. Although the shortening of the obtained delays that followed the transition to the signaled condition in Pigeons 422 and 269 may have contributed to the increases in response rates, the lack of change in the obtained delays for the other 2 subjects (particularly Pigeon 407) indicates that it is not necessary for producing the increases.

Although increased rates of responding were observed under the 3-s briefly signaled delay to reinforcement, it is not known whether the maintenance of rates during the 9-s delay phase depended on experience with briefly signaled delay at the shorter (3 s) delay. Experiment 3 was performed to determine whether low rates of pecking under a 9-s unsignaled delay to reinforcement could be increased and maintained when delays were briefly signaled. An attempt also was made to equate reinforcement frequency across conditions of immediate, unsignaled, and briefly signaled delay to reinforcement.

EXPERIMENT 3

METHOD

Subjects

Two experimentally naive, adult male White Carneau pigeons (*Columba livia*) were used. Conditions of deprivation, care, and maintenance were the same as in the previous experiments.

Table 3

Summary of conditions, number of sessions per phase, and reinforcement rates for each subject obtained during the final session of each experimental phase in Experiment 3.

Condition	Subjects			
	766		869	
	Sessions	Reinforcers per minute	Sessions	Reinforcers per minute
TAND VT 60 s FI 9 s (no delay)	54	0.86	55	0.87
TAND VI 60 s FT 9 s (unsigned delay)	25	0.57	25	0.66
CHAIN VI 60 s FT 9 s (briefly signaled delay)	88	0.87	89	0.86
TAND VT 60 s FI 9 s (no delay)	47	0.86	47	0.86

Apparatus

A standard Lehigh Valley Electronics pigeon conditioning chamber (Model 1519) was used. Its internal dimensions were 30.5 cm long, 35.5 cm wide, and 35 cm deep. The side and back walls and the ceiling were white, and on the chamber's door was mounted a one-way window that was covered from the outside with cardboard when subjects were not being observed. The front wall of the chamber was a brushed aluminum panel with three 2.5-cm diameter response keys centered side-to-side 24.5 cm above the wire-mesh floor. Only the middle key, which could be lighted from behind with a green or red light, was used; the side keys were dark and inoperative. The middle key required a force of approximately 0.17 N to produce a 60-ms feedback tone (Mallory Sonalert) and be recorded as a response. A 28-V 1.1-W lamp 8 cm directly above the middle key and shielded by a stainless steel cap that reflected the light upwards served as a houselight. A 5.2-cm by 5.7-cm rectangular aperture 9 cm below the middle key provided access to a solenoid-operated food hopper. During hopper presentations this aperture was lit with a 28-V 1.1-W white light, and the houselight and keylight were extinguished. Other features of the apparatus were the same as in Experiments 1 and 2.

Procedure

Preliminary procedures were identical to those used in Experiments 1 and 2. Sessions were conducted 7 days per week. The baseline schedule was a tandem variable-time (VT) 60-s fixed-interval (FI) 9-s schedule of food reinforcement, which consisted of 4-s access to the hopper. After rates of response had become stable, the schedule was changed to a tandem

VI 60-s FT 9-s schedule. The first schedule, then, was the immediate-reinforcement schedule, because the first peck that occurred after the FI 9 s had elapsed was reinforced immediately. The schedule that followed was a VI 60-s schedule with a 9-s unsigned nonresetting delay to reinforcement. After response rates had become stable on this schedule, a 0.5-s change in key color (from green to red) was arranged to follow immediately the peck that began the 9-s delay (i.e., the delay was briefly signaled). When rates of pecking had stabilized under this schedule, the initial tandem VT 60-s FI 9-s schedule was reintroduced for 15 sessions. As in Experiments 1 and 2, rates of pecking during the VT 60-s or VI 60-s schedule, obtained delays to reinforcement, responses during the brief signal and during the delay, and cumulative records were collected daily. The order of experimental conditions and rates of reinforcement obtained in the final sessions of each phase are shown in Table 3.

RESULTS

Cumulative records from both subjects (Figure 10) show performance representative of that observed during immediate-reinforcement conditions and unsigned and briefly signaled delays to reinforcement. A steady rate of key pecking typical of that engendered by VI schedules developed under the baseline TAND VT 60-s FI 9-s schedule (labeled "0 SEC" in the figure). Rates decreased substantially and response patterns included relatively long periods with no pecks when the schedule was changed to a TAND VI 60-s FT 9-s schedule (unsigned delay; 9 SEC:NS). Response rates increased and typical VI patterns were recovered when a 0.5-s brief signal began the delay (9 SEC:S).

Session-to-session response rates are depicted in Figure 11. Stable immediate-reinforcement baseline rates (0 SEC) were followed by systematically decreasing rates under the 9-s unsigned delay phase (9 SEC:NS). Rates of responding during this phase became stable at levels below 10 responses per minute. As shown in Table 3, reinforcement rates during the final session of this phase were lower for both pigeons than those observed in the previous and subsequent phases. When the 9-s delay was briefly signaled, rates of pecking increased. The increase was slow, however, because rates of pecking did not increase at all for Pigeon 766 across the first 10 sessions, and rates for Pigeon 869 increased only slightly during these sessions. When delays were briefly signaled rates for Pigeon 766 became stable at a level approximately 40 responses per minute higher than immediate-reinforcement levels. For Pigeon 869 the corresponding rates became stable at a level 20 to 30 responses per minute lower than immediate-reinforcement levels. When the TAND VT 60-s FI 9-s schedule was reinstated ("0 SEC" in the right-most part of Figure 11) pecking at first became more variable, but became stable at rates lower than those observed in the previous phase for Pigeon 766 (nearer immediate-reinforcement baseline levels) and higher than those observed in the previous phase for Pigeon 869 (again, nearer immediate-reinforcement baseline levels). Rates of reinforcement did not differ appreciably during the final sessions of immediate-reinforcement conditions or the briefly signaled delay condition (see Table 3).

Figure 12 shows obtained delay distributions during the final sessions under unsigned 9-s delay conditions and briefly signaled 9-s delay conditions for both subjects. The first second of the delay (obtained delay, 8.1 to 9.0 s) is represented again to the right of the entire distribution, resolved to 0.1 s to reveal details of changes in this part of the distribution. Obtained delays were distributed across most of the delay under conditions of unsigned delays to reinforcement, with the modal delay equaling 9 s. When the delay was briefly signaled, obtained delays were distributed across the period that would result from responding when the brief signal was lit (8.5 to 9.0 s), with no other pecking during the delay. These distributions are similar to those shown in the right panel of Figure 4 (Experiment 1) during the

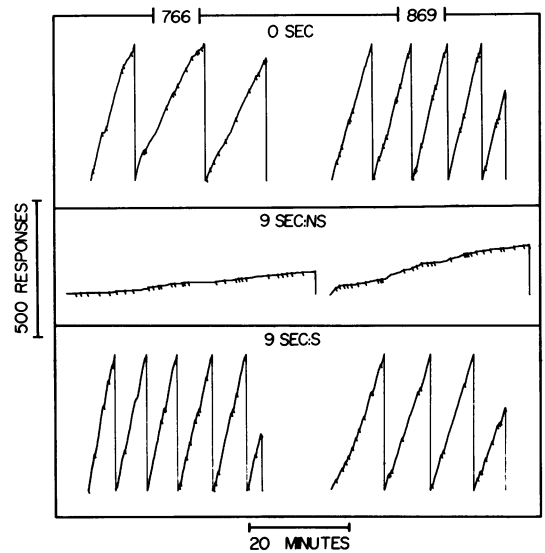


Fig. 10. Cumulative response records showing performances of Pigeons 766 (left records) and 869 (right records) in Experiment 3 during the TAND VT 60-s FI 9-s immediate-reinforcement schedule (0 SEC), 9-s unsigned delay to reinforcement (9 SEC:NS), and 9-s briefly signaled delay to reinforcement. Y axes, cumulative key pecks; X axes, time. Short diagonal marks indicate food presentations. The cumulative recorder operated during delays. Key-peck rates in the sessions from which these records were selected were near the mean of the final five sessions of each phase.

second exposure to the 9-s briefly signaled delay phase.

DISCUSSION

The pigeons' response rates decreased to very low levels under a TAND VI 60-s FT 9-s (delayed reinforcement) schedule. When the delay was briefly signaled, rates increased gradually to levels well above those observed when the delay was unsigned. For Pigeon 766 rates under the briefly signaled delay condition were much higher than those observed under baseline; for Pigeon 869 rates were lower than baseline under this condition. When a TAND VT 60-s FI 9-s (immediate reinforcement) schedule was reimposed, response rates returned to near their initial immediate-reinforcement baseline levels. Increases in response rates relative to those observed under unsigned delay to reinforcement conditions were similar to those observed in Experiments 1 and 2, and thus did not require prior exposure to shorter (i.e., 1 s and 3 s) briefly signaled delays.

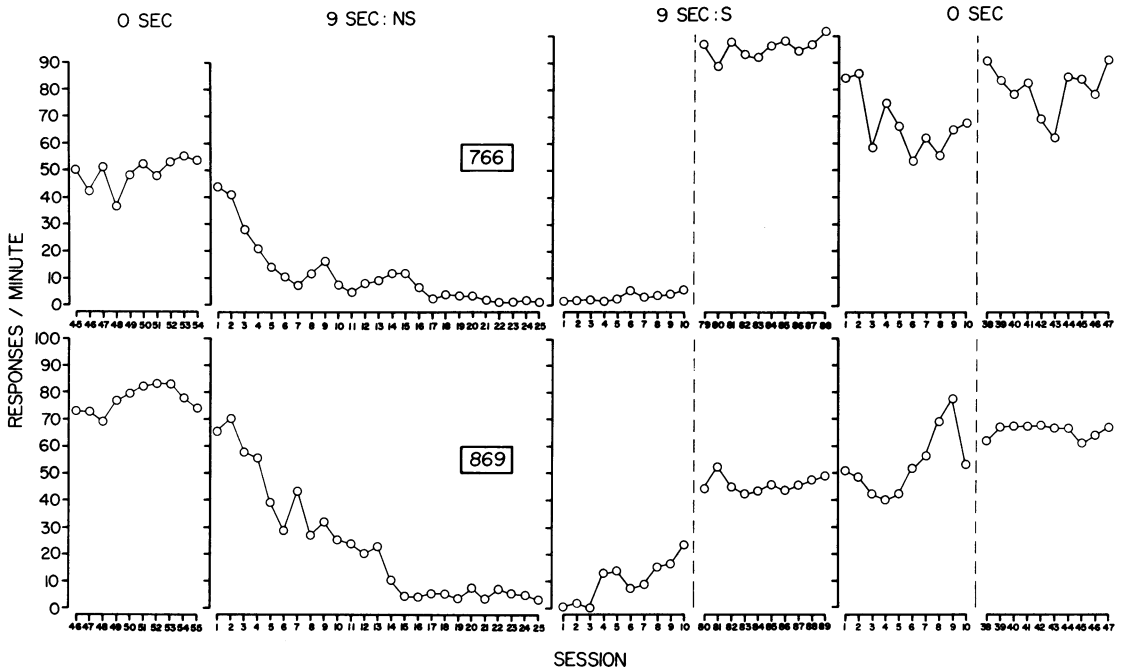


Fig. 11. Rates of key pecking, exclusive of time during delays, for both subjects (766 and 869) in Experiment 3 during the last 10 sessions of the first immediate-reinforcement condition (far left, 0 SEC) during every session of the 9-s unsignaled delay condition (9 SEC: NS), during the first and last 10 sessions of the 9-s briefly signaled delay condition (9 SEC: S), and during the final immediate-reinforcement condition (far right, 0 SEC). Sessions were numbered beginning at one in each phase. Dashed vertical lines separate data from the first 10 and last 10 sessions of a phase.

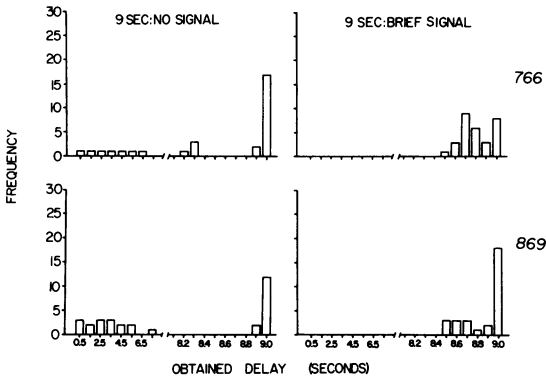


Fig. 12. Frequency distributions of obtained or actual delays to reinforcement for both subjects in Experiment 3 during the last session of the unsignaled 9-s delay condition (left panels) and the last session of exposure to the 9-s briefly signaled delay condition (right panels). Distributions are representative of those collected in the last five sessions of these conditions. Obtained delays to reinforcement between 8.1 and 9.0 s are resolved to 0.1 s; the total frequency of obtained delays in the 8.1 to 9.0-s bin may be obtained by summing across 0.1-s bins. Those less than 8.0 s are resolved to 1.0 s.

The obtained delay distributions shown in Figure 12 are similar to those obtained in the second exposure to the 9-s delay condition in Experiment 1 (see Figure 4), in that all obtained delays were between 8.5 and 9.0 s. This indicates that no pecks occurred following the withdrawal of the brief stimulus. Median obtained delays observed during the second exposure to the 9-s briefly signaled delay component in Experiment 2 (Figure 8), however, indicate that pecks did occur following the withdrawal of the brief signal. The variables responsible for pecking following the brief signal require further research, but, taken together, the data suggest strongly that accidental response-food contiguities are not necessary for the maintenance of relatively high response rates under conditions of briefly signaled delayed reinforcement.

In this experiment, an attempt was made to keep rates of reinforcement as constant as possible across experimental phases. The reinforcement schedules were arranged so that only the temporal location of the peck that produced reinforcement differed across phases (i.e., in

the initial immediate-reinforcement schedule the peck that produced food was also contiguous with food), whereas in the delayed-reinforcement schedules the peck that produced food occurred 9 s prior to presentation of the hopper. Because of the substantial decrease in response rates under the unsigned delay condition, however, reinforcement rates were not held constant (see Table 3), and the differences across conditions may be partly responsible for the changes in response rates. The transition to briefly signaled delayed reinforcement may have produced a change in response patterns (e.g., a reduction in the frequency of the long pauses observed under the unsigned delay condition) that increased the frequency of primary reinforcement, which thereby contributed to the increase in response rates. The arrangement of the schedules does permit a direct comparison of rates of response under immediate-reinforcement and briefly signaled delayed reinforcement conditions, because reinforcement frequencies in these conditions did not differ appreciably. This comparison shows that substantial differences in response rates (20 to 40 responses per minute) can be obtained under essentially identical frequencies of primary reinforcement. This suggests that variables in addition to reinforcement frequency are operating.

GENERAL DISCUSSION

Rates of pecking comparable to those obtained under conditions of immediate reinforcement and higher than those obtained under equal unsigned delays were observed under VI 60-s schedules of briefly signaled delayed reinforcement at 1-, 3-, and 9-s delays, but not at 27-s delays. When delays to reinforcement were completely signaled (Experiment 2), near-baseline response rates were maintained across all of the delay values tested (3, 9, and 27 s). The higher rates under briefly signaled delay conditions were not reliably correlated with shorter obtained delays to reinforcement, although under some conditions shorter obtained delays may have played a role in the rate increases observed upon transition from unsigned to briefly signaled delays (e.g., from 1-s unsigned to briefly signaled delays in Experiment 1; see Figure 3). Decreases in the frequencies of primary reinforcement (food; see Tables) were often observed under con-

ditions in which response rates decreased to low levels, particularly the 27-s briefly signaled delay conditions of Experiments 1 and 2 and the 9-s unsigned delay phase of Experiment 3. In each case the changes in reinforcement frequency may have contributed to the response rates obtained, but the comparison of reinforcement frequencies in briefly signaled to completely signaled delay components in Experiment 2 suggests that these changes alone do not adequately account for the changes in response rates. We are led to consider the interpretation that the brief stimuli that signaled the reinforcement delay in the present experiments can be called conditioned reinforcers, which, when presented immediately following responses, increased and maintained high response rates.

Conditioned-reinforcement interpretations of the maintenance of relatively high response rates under delayed-reinforcement conditions have been considered before. Ferster (1953), for example, explained the maintenance of key pecking under a VI 60-s schedule with a signaled 1-min delay to reinforcement by characterizing the situation as a chained schedule, in which response rates in the initial link (VI 60 s) of the chain were maintained by entry into the terminal link (i.e., the delay). In his interpretation, some behavior (not key pecking) was reinforced with food at the end of the delay, and, when the delay was lengthened gradually, the "superstitious" behavior was maintained, thereby "bridging the gap" introduced by the delay. The delay signal became a discriminative stimulus for the adventitiously reinforced behavior and, as a result, became a conditioned reinforcer that maintained response rates during the initial link. In the present study, according to that interpretation, the stimulus changes (both brief and complete) that signaled delays to reinforcement maintained response rates because they were discriminative stimuli for some behavior that was reinforced adventitiously at the end of the delay. When response rates were not well maintained (e.g., in the 27-s briefly signaled delay conditions of Experiments 1 and 2) it was because the immediate stimulus change did not function as a discriminative stimulus for some "gap-bridging" behavior.

The "discriminative-stimulus hypothesis" of conditioned reinforcement cannot be rejected on the basis of the present results, es-

pecially considering data that show that discriminative stimuli can function as reinforcers (e.g., from "observing" experiments; see Wyckoff, 1952). However, the interpretation is compromised by several factors. It has been shown, for example, that the discriminative function of stimuli in extended chained schedules can be separated from their reinforcing function (Kelleher & Fry, 1962). Also, the specific nature of the behavior of pigeons under schedules of response-independent food presentation is, at present, in question. The order observed in pigeons' behavior under these conditions may not be related specifically to accidental temporal contiguities of certain topographies with food (i.e., they may not be properly called "superstitious operants"; Timberlake & Lucas, 1985). Because response-independent schedules prevailed during the programmed delays in the present study, it may be premature to attribute the conditioned reinforcing function of the brief stimulus to its function as a discriminative stimulus for superstitious operant behavior. Finally, the discriminative-stimulus hypothesis of conditioned reinforcement makes no predictions regarding the higher response rates observed in 3 of 4 subjects in the completely signaled delay component compared to the component with brief signals during the 27-s delay phase (Experiment 2). Even if it were necessary for the brief stimulus to exert discriminative control over intradelay behavior, why is control exerted over a limited temporal range relative to the stimulus that remains in place throughout the delay period? An interpretation is needed that includes the differences revealed in Experiment 2.

It is possible that the effectiveness of the brief stimulus as a conditioned reinforcer can be predicted from the keylight-food relationship that is required to establish a brief keylight stimulus as a conditional stimulus in a trace autoshaping paradigm (e.g., Kaplan, 1984; Kaplan & Hearst, 1982; Lucas et al., 1981; Newlin & LoLordo, 1976). If this were the case, one might expect measures of pecking during the delay signals to reflect this respondent (Pavlovian) relationship. Previous research (e.g., Kaplan, 1984; Lucas et al., 1981) has shown that key-directed behavior decreases as the CS-US interval increases. Pigeon 165 (Figure 5) and Pigeons 269, 422, and 4582 (Figure 9) failed to show the pre-

dicted effect, however. In fact, Figure 9 reveals that for these subjects the average number of pecks during the brief signal actually increased across the delay values, reaching a peak during the 27-s briefly signaled delay phase, during which the brief signal failed to maintain near-baseline rates of operant pecking. These data, as mentioned earlier, suffer interpretive problems because they may show either respondent key pecking or shifts in overall IRT distributions across phases. If they can be taken as measures of respondent pecking, they seem to refute the notion that the respondent relations between primary reinforcers and other stimuli are an important determinant of the conditioned reinforcing efficacy of the other stimuli. It could be, however, that respondent relations (i.e., the temporal-correlative relation between the brief stimulus and food) determine only *whether* a stimulus will acquire some function; precisely what that function is ("eliciting" or "reinforcing") depends on other procedural aspects, most notably the response-dependent or response-independent arrangement between behavior and brief stimuli. Under certain temporal arrangements between brief stimuli and reinforcement, the brief stimulus will elicit key pecking if presented response independently, and it will maintain high rates of operant pecking if made contingent on pecks. As the time between brief stimulus presentation and food is increased, the brief stimulus will function neither as conditional stimulus nor as conditioned reinforcer.

The present results support the above notion in two ways. First, the superiority of conventional "delay conditioning" procedures to trace conditioning in autoshaping (e.g., Newlin & LoLordo, 1976) is consistent with the effect observed in Experiment 2, in which rates of response in the completely signaled delay component were well maintained relative to rates in the briefly signaled delay component. Second, response rates remained high when the briefly signaled delay was 9 s long, but usually fell to low levels when the delay was lengthened to 27 s. This decrease in rates would be expected under the current interpretation, because it has been shown that stimulus-directed behavior under trace-autoshaping arrangements decreases as the CS-US interval is increased (Lucas et al., 1981).

These similarities are compelling enough to prompt our examining some of the effects of

response-dependent brief stimuli that signal delays to reinforcement that would be predicted under this interpretation. For example, it has been shown that the range of CS-US intervals over which trace CSs elicit responding increases as the average ITI increases (Kaplan, 1984). This suggests that increasing (or decreasing) the value of the VI schedule should in turn increase (or decrease) the maximum delay at which response rates will be maintained by the brief signal. Also, Gamzu and Williams (1973) showed that when keylight illumination and food were presented independently of each other (i.e., no correlation) pigeons pecked the key much less often than when there was a positive correlation between keylight presentation and food (see also Gibbon, Locurto, & Terrace, 1975). Presenting the brief stimulus response dependently but independently of food presentation, manipulating the percentage of delays to reinforcement signaled by the brief stimulus (e.g., Lattal, 1984) or delivering "extra" brief stimuli uncorrelated with food all modify the correlation of brief stimulus with food, and therefore should help determine the workability of this respondent-conditioning interpretation of the conditioned-reinforcing function of the delay signals. Interestingly, Lattal (1984) found that response rates under un signaled delay conditions with superimposed response-dependent 20-s chamber blackouts that were negatively correlated with the delays (and, hence, with food presentation) differed little, for most pigeons, from the low rates observed under un signaled delay conditions without the blackouts. When chamber blackouts actually signaled the delay (as signals did in the present study) responding was maintained at rates nearer to those observed under immediate reinforcement. In another experiment, Lattal showed that rates of pecking under a 20-s completely signaled delay of reinforcement approached immediate-reinforcement baseline rates only as the percentage of the delays that were signaled was increased to 100%; when only 66% of the delays were signaled, rates fell below 50% of those observed under immediate reinforcement for 4 of 5 pigeons. These results support the contention that a positive correlation between delay signals and reinforcement is required for those signals to maintain high response rates, and, thus, support the interpretation proposed here.

The suggestion that it is the relative length of the trace interval (delay) that is important for determining classical conditioning to and the conditioned-reinforcing efficacy of the brief stimulus is consistent with Fantino's delay-reduction hypothesis of conditioned reinforcement (Fantino, 1977). According to this notion, the efficacy of a stimulus as a conditioned reinforcer is determined by the reduction in delay to reinforcement signaled by the stimulus, calculated relative to the overall average time between food presentations. If the delay-reduction hypothesis can be extended to single-key situations like the present one, it should predict greater conditioned reinforcing efficacy of the brief stimulus (and, hence, higher response rates) under the 9-s delay than under the 27-s delay, as was observed. The brief stimulus also should maintain higher response rates at the 1- and 3-s delays than at the 9-s delay. In many of the subjects in the present experiments, however, response rates were highest during 9-s delay conditions. The increased rates observed frequently under briefly signaled delay conditions relative to immediate-reinforcement baseline conditions in these experiments are difficult to interpret under any of the explanations considered here, and additional experiments are required to determine the variables responsible for them.

In closing, it should be noted that we are not advocating a respondent-conditioning interpretation of all operant functions (discriminative, reinforcing, etc.) of stimuli that are not primary reinforcers. Operant and respondent functions of stimuli are often separable. Marcucella (1981), for example, showed that pigeons pecked a key when it was lit briefly with a stimulus that preceded a period of VI reinforcement more often than a different color key that preceded a period of extinction (thus reflecting the respondent relationship between the key and subsequent reinforcement), whereas operant key pecking following the two brief stimulus presentations occurred at nearly the same rate, indicating no discriminative control by the brief stimuli. It may be that further experimentation will allow us to separate the reinforcing from the discriminative and respondent functions of stimuli that signal delays to reinforcement. At this point, however, the trace-autoshaping approach to these data suggests several interesting experiments that could establish an important role for re-

spondent relations in determining the operant functions of stimuli.

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