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A COMPARISON OF SIGNALED AND UNSIGNALED DELAY OF REINFORCEMENT

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Pigeons were trained on either a variable-interval 60-second schedule, or on a schedule that differentially reinforced responses that were spaced at least 20 seconds apart. The birds were then exposed to several durations of reinforcement delay, with comparisons between signaled and unsignaled delays. Although unsignaled delays of 5 and 10 seconds produced large decreases in response rate, signaled delays of up to 10 seconds produced only moderate decreases in response rates. In addition, some subjects responded more rapidly with a .5 or 1.0 second duration of unsignaled delay than with immediate reinforcement. These response rate changes occurred regardless of whether the rate of reinforcement concomitantly decreased or increased.

Key words: reinforcement delay, variable-interval schedule of reinforcement, differential-reinforcement-of-low-rates schedule of reinforcement, key peck, pigeons

One of the most widely discussed parameters of reinforcement is delay of reinforcement (e.g., Bolles, 1975; Hulse, Deese, & Egeth, 1975; Mackintosh, 1974). While much of the early empirical and theoretical work examined the manner in which delayed reinforcement influenced the learning of new behavior or discriminations (e.g., Grice, 1948; Perin, 1943; Spence, 1947; Wolfe, 1934), the more recent emphasis, especially in the area of operant conditioning, has been on how it affects behavior maintained by various schedules of reinforcement (e.g., Azzi, Fix, Keller, & Rocha e Silva, 1964; Dews, 1960; Ferster, 1953; Ferster & Hammer, 1965; Morgan, 1972; Pierce, Hanford, & Zimmerman, 1972; Silver & Pierce, 1969; Sizemore & Lattal, 1977, 1978; Williams, 1976).

Delayed reinforcement actually refers to a collection of very different manipulations. For example, the delay period may be signaled or unsignaled; if signaled, the opportunity to respond may or may not be withdrawn during the delay. In addition, responding during the delay interval may be nonfunctional or it may be penalized, e.g., by resetting the delay interval. Given this diversity, it would be surprising if all such manipulations had identical effects. Yet, few researchers have actually compared different types of delayed reinforcement within the same experiment. In probably the most systematic study to date, Pierce et al. (1972) trained rats on a variable-interval (VI) schedule and examined several types of signaled delay. Although response rates were found to decrease as the duration of the delay was increased, the manner in which the delay interval was signaled had little effect. More recently, Williams (1976) has suggested that delayed reinforcement will maintain much lower rates of responding if the delay interval is unsignaled rather than signaled. Unfortunately, Williams examined only unsignaled delay and made this suggestion after comparing data obtained with vastly dissimilar procedures in different studies. In support of Williams' suggestion, Richards and Hittesdorf (1978) found that a 10-sec signaled delay maintained much higher response rates than a 10-sec unsignaled delay when pigeons' responding was reinforced according to a VI schedule.

The purpose of the present experiment was to assess the generality of Richards and Hittesdorf's finding by comparing the effects of various durations of signaled and unsignaled delay. To assess the generality of any effect, the present experiment also included two different types of reinforcement schedules. Variable-interval 60-sec and differential-reinforcement-of-low-response-rates (DRL) 20-sec schedules were selected because it seemed possible that delayed reinforcement might produce similar effects on the behavior maintained by these

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schedules (i.e., decreased response rates) and dissimilar effects on reinforcement rates. On the one hand, a decrease in responding under a VI 60-sec schedule (which schedules reinforcement for the first response after the elapse of various intervals that average 60 sec) should lower reinforcement rates. On the other hand, a decrease in responding under a DRL 20-sec schedule (which schedules reinforcement for the first response after a 20-sec pause in responding) could increase reinforcement rates, given the inefficient DRL performance (i.e., low reinforcement rates) typically shown by pigeons (Reynolds, 1964a, 1964b). If, in spite of these differences, the comparison between signaled and unsignaled delay produced a similar outcome, it would strengthen substantially the generality of the findings.

METHOD

Subjects

Nine experimentally naive, female, adult White Carneaux pigeons were maintained at approximately 80% of their free-feeding weights. One subject in the DRL condition failed to continue responding and was discarded after approximately 75 sessions of training; data from this subject are not reported.

Apparatus

Two operant conditioning chambers were employed. One chamber (internal dimensions: 37 cm long by 32.5 cm wide by 33 cm high) was constructed of plywood, except for a metal front wall and an acrylic plastic window on a sidewall. The center key required a force of approximately .15 N to operate and was illuminated by a white light from a Kodak slide projector; the side keys were covered with cardboard. Three houselights (white) and a pilot light (green) were mounted on the front and back walls, respectively. The other chamber (internal dimensions: 30.5 cm long by 35 cm wide by 35 cm high) was obtained from Lehigh Valley Electronics and also contained three houselights (white) and a pilot light (yellow). The right key in this chamber was illuminated by a green light (24ESB bulb) and required a force of approximately .15 N to operate; the center key was covered with tape, and the left key was dark and nonfunctional. The illumination of houselights and pilot lights in both chambers were provided by CM 1820 bulbs. The chambers also contained a photocell system that timed access to the mixed grain reinforcer.

The chambers and standard electromechanical equipment were located in separate rooms.

Procedure

Variable-interval. The four subjects assigned to the variable-interval condition received preliminary training during which the key peck was shaped and the frequency of reinforcement was gradually reduced until a VI 60-sec schedule was attained. Reinforcement was never delayed during these sessions, which terminated after 40 reinforcers were delivered.

Subjects then received 48 1-hr sessions with each of the following durations of reinforcement delay in the order listed: 10-, 5-, 2.5-, 1-, and .5-sec. B-5203 and B-9072 received the signaled delay during the first 24 sessions and the unsignaled delay during the last 24 sessions of each 48-session block; the order of the signaled and unsignaled delay conditions was reversed for B-2788 and B-2334. During the signaled delay, the keylight and houselights were darkened and the pilot light illuminated; no stimulus change occurred during the unsignaled delay. Responses during either type of delay were nonfunctional and were not recorded. The keylight and houselights were illuminated during presentation of the reinforcer. The tape timer that scheduled reinforcement availability stopped once reinforcement became available and restarted at the end of the reinforcement period. After the aforementioned delay sequence was completed, subjects received 24 1-hr sessions of immediate reinforcement under the VI 60-sec schedule. Throughout, the reinforcer was 2-sec access to mixed grain, the timing of which began when the photobeam in the food magazine was broken. Two subjects were trained in each chamber.

Differential reinforcement of low rates. Preliminary training for the remaining subjects included shaping of the key peck, three sessions with a continuous-reinforcement schedule, and one session with a fixed-interval 20-sec schedule. Reinforcement was not delayed during these sessions, which terminated after 40 reinforcers were delivered.

Thereafter, subjects were trained on a DRL 20-sec schedule, and sessions terminated after 1 hr or 60 reinforcers were obtained, whichever occurred first. The clock that scheduled the availability of reinforcement stopped once reinforcement became available and restarted at the end of the reinforcement period. Responses during delay and reinforcement periods were nonfunctional and were not recorded. Other aspects of the procedure were identical to those employed in the VI condition. B-3340 and B-11629 received the signaled delay before the unsignaled delay at each duration of delay, and B-5843 and B-1926 received the unsignaled delay before the signaled delay. Subjects were trained in the Lehigh Valley Electronics chamber.

Results

Figure 1 shows the mean response rate during the last six sessions under the various durations of signaled (filled symbols) and unsignaled (unfilled symbols) delay for each subject trained under the VI 60-sec schedule. The brackets indicate one standard deviation above and below the mean. Since the keylight was darkened during only signaled delay intervals, the responses and time during all delay periods were omitted from computations of these statistics in order to make the measures for the two delay conditions more comparable. The most striking characteristic of Figure 1 is the differing slopes of the functions. The relatively flat functions for signaled delay indicate that only moderate decreases in response rates occurred with signaled delays of up to 10 sec. In contrast, the steep functions for unsignaled delay show that large decrements occurred with 5- and 10-sec durations of unsignaled delay. In fact, as Table 1 shows, subjects responded so slowly with the longer unsignaled delays that

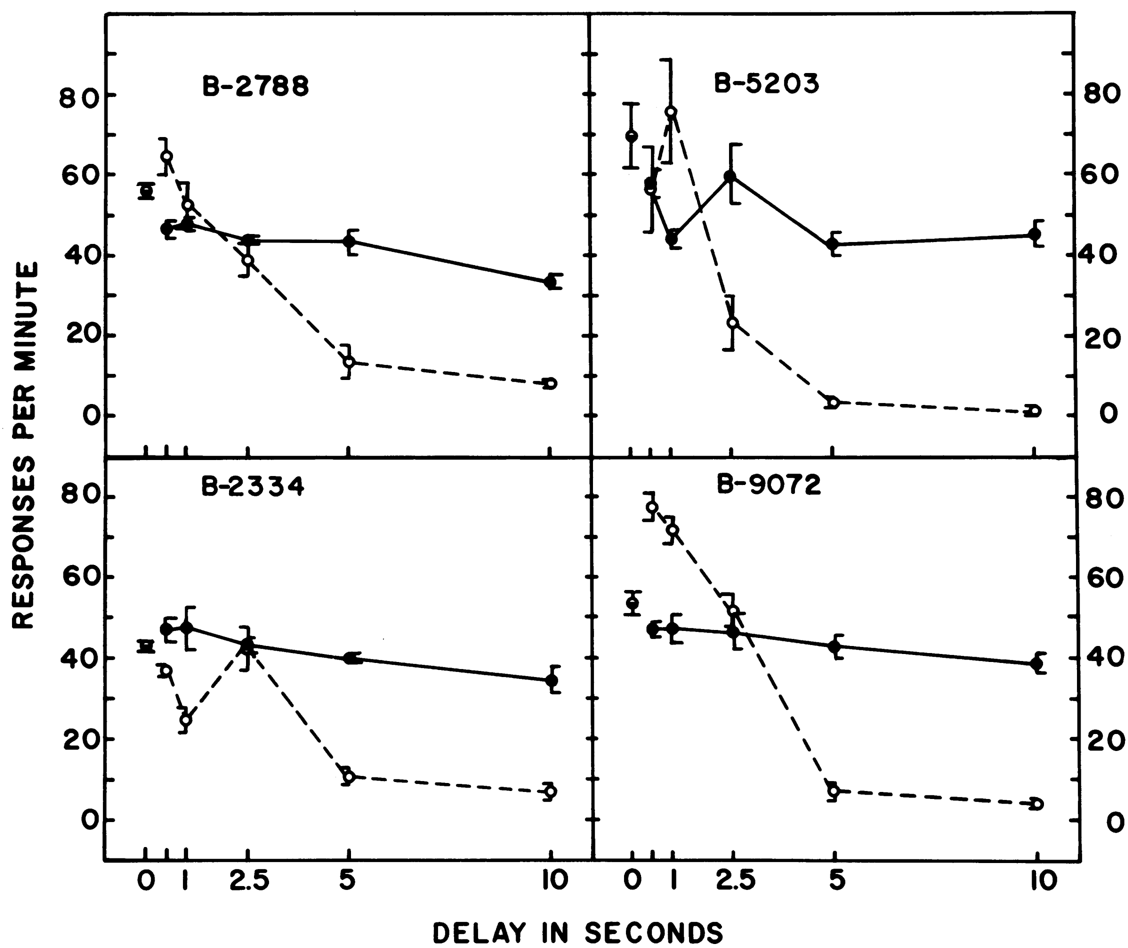

Fig. 1. Mean rate of response during the last six sessions at each duration of signaled (filled circles) and unsignaled (unfilled circles) delay of reinforcement with a VI 60-sec schedule. Brackets indicate one standard deviation above and below the means.

not all scheduled reinforcements were obtained.

Figure 1 also shows that whether subjects responded more rapidly under unsignaled or signaled delay depended on the delay duration. Although all subjects responded more rapidly under the 5- and 10-sec delays when the delay interval was signaled rather than unsignaled, there was less consistency at the shorter delay durations. With a delay of 2.5 sec, B-5203 responded more rapidly under signaled delay, but the other subjects responded at about the same rate under both delay conditions. When reinforcement was delayed for 1 sec, B-9072 and B-5203 responded more rapidly under unsignaled delay, B-2334 more rapidly under signaled delay, and B-2788 at about the same rate under both delay conditions. With a .5-sec delay, B-9072 and B-2788 responded more rapidly under unsignaled delay, B-2334 more rapidly under signaled delay, and B-5203 at about the same rate under signaled and unsignaled delay. It should also be noted that B-9072 and B-2788 responded more rapidly during the .5-sec unsignaled delay than the immediate reinforcement condition; B-9072 also responded more rapidly under the 1-sec unsignaled delay than the immediate reinforcement condition.

Casual observations indicated that subjects rarely pecked the key during signaled delay intervals, but that they frequently paced and waved their heads back and forth along the front wall and sometimes pecked at the darkened houselights, at least during the longer delays. Casual observation also indicated that subjects frequently key pecked during unsignaled delays, especially when delay durations were 2.5 sec or less.

Figure 2 shows the mean response rate during the last six sessions under the various durations of signaled (filled symbols) and unsignaled (unfilled symbols) delay for each subject trained under the DRL 20-sec schedule; the brackets represent one standard deviation above and below the mean. It is readily apparent that each subject produced a flatter function under signaled than unsignaled delay. Three data points are missing for B-3340 because its responding was not maintained by the 10-sec signaled delay (perhaps because this was its first delay condition), and because its health deteriorated before training under the last two conditions could be completed. Figure 2 clearly shows that the remaining three subjects had much higher response rates when the 10-sec delay was signaled rather than unsignaled; more rapid responding also occurred when the delay interval was signaled at the 5-sec delay duration. With a 2.5-sec delay, B-3340 and B-5843 continued to show higher response rates under signaled delay, but B-11629 and B-1926 showed nearly equivalent response rates under both delay conditions. With a 1- and .5-sec delay, these latter two subjects showed higher response rates when the delay interval was unsignaled; in fact, their response rates were even higher with a brief unsignaled delay than with immediate reinforcement. B-3340 showed higher response rates with a 1-sec signaled than unsignaled delay. Finally, B-5843 showed response rates under the .5- and 1-sec signaled and unsignaled delays that were nearly equivalent to its response rate under immediate reinforcement.

Although subjects' behavior during the delay intervals was not systematically observed,

Table 1
Reinforcements per minute obtained during the last six sessions in each phase with the VI schedule[a].

Bird	*B-2788*		*B-2334*		*B-5203*		*B-9082*	
delay (sec)	*S*[b]	*U*[c]	*S*	*U*	*S*	*U*	*S*	*U*
.0	.99		.96		.97		.97	
.5	.99	.99	.95	.92	.99	.99	.98	.96
1.0	.98	.98	.98	.92	.99	.98	.98	.96
2.5	.99	.95	.95	.96	.99	.94	.96	.94
5.0	.98	.93	.96	.91	1.00	.76	.96	.78
10.0	1.00	.88	.87	.84	1.00	.52	.96	.68

[a]Based on session durations exclusive of delay and reinforcement periods
[b]Signaled delay
[c]Unsignaled delay

it was not uncommon for birds to peck during the unsignaled delay intervals, especially at briefer delay durations. In addition, B-1926 frequently key pecked during the 10-sec signaled delay intervals, and B-11629 key pecked during many of the signaled delay intervals, regardless of their duration.

Table 2 shows that each subject in the DRL condition generally obtained much higher rates of reinforcement at the longer delay durations, especially when the delay interval was unsignaled. Table 3 shows the percent of responses that were reinforced during the last six sessions of each condition and indicates that subjects were more efficient at obtaining reinforcement with the longer unsignaled delays (i.e., a high percentage of their key pecks were reinforced) than with any of the other conditions.

DISCUSSION

Signaled delays of up to 10 sec imposed during either a VI 60-sec or DRL 20-sec schedule produced only moderate decreases in subjects' responding, whereas unsignaled delays of 5 and 10 sec similarly imposed produced large decreases in subjects' responding. These findings confirm and extend the findings of Richards and Hittesdorf (1978) that were obtained with a 10-sec delay and a VI 60-sec schedule in a multiple-schedule design. It should also be noted that previous research with a VI schedule has frequently obtained only moderate re-

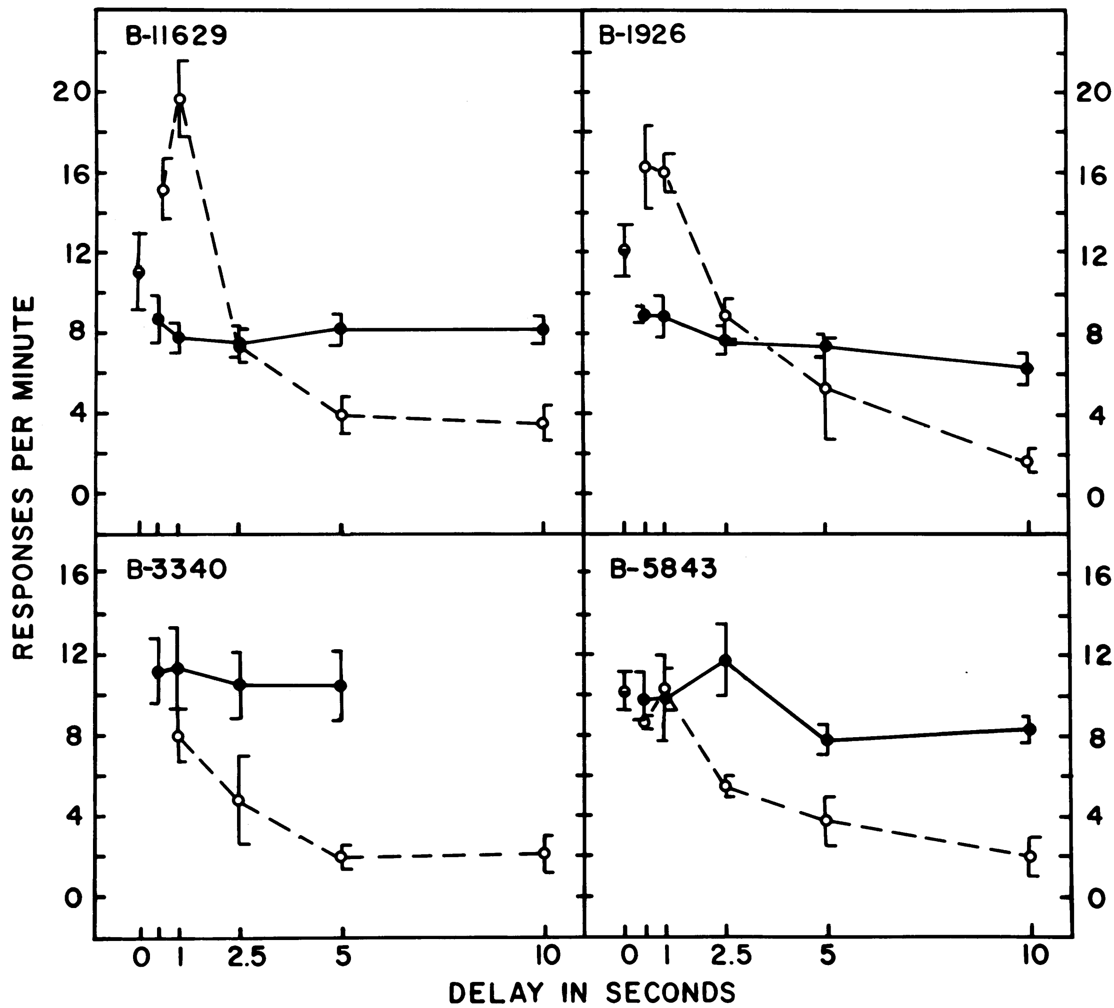

Fig. 2. Mean rate of response during the last six sessions at each duration of signaled (filled circles) and unsignaled (unfilled circles) delay of reinforcement with a DRL 20-sec schedule. Brackets indicate one standard deviation above and below the mean.

Table 2

Reinforcements per minute obtained during the last six sessions in each phase with the DRL schedule[a].

Bird / delay (sec)	B-3340		B-11629		B-5843		B-1926	
	S[b]	U[c]	S	U	S	U	S	U
.0	—		.19		.04		.05	
.5	.08	—	.16	.23	.04	.07	.05	.05
1.0	.06	.44	.08	.17	.08	.13	.09	.16
2.5	.07	.83	.16	.69	.06	.56	.09	.61
5.0	.14	1.10	.10	1.09	.14	.98	.13	.99
10.0	—	.87	.12	1.42	.13	.96	.45	1.02

[a]Based on session durations exclusive of delay and reinforcement periods
[b]Signaled delay
[c]Unsignaled delay

ductions in response rates from the immediate reinforcement condition with signaled delays of less than 5 or 10 sec (e.g., Pierce et al., 1972; Richards, 1972; Wilkie, 1971) and large reductions with unsignaled delays of 3 sec or longer (Sizemore & Lattal, 1977, 1978; Williams, 1976). Sizemore and Lattal (1978) also reported that response rates frequently were maintained at a higher level by brief unsignaled delays than by immediate reinforcement; half of the subjects in the present experiment showed this effect. Overall then, the shapes of the delay-of-reinforcement functions obtained in the present study with signaled and unsignaled delay are similar to those obtained in previous studies with a VI schedule. A major contribution of the present study was that the gradients were obtained with similar procedures in a within-subjects design and regardless of whether responding was reinforced according to a VI or DRL schedule.

The different shapes of the signaled and unsignaled delay functions obtained in the present study on response-maintenance are reminiscent of the functions obtained in the classic studies on reinforcement delay and new learning by Perin (1943) and Grice (1948). Clearly, both response-acquisition and response-maintenance functions vary dramatically depending on whether the delay interval is signaled or unsignaled. Future attempts to quantify the law of effect along the lines suggested by Herrnstein (1970) and de Villiers (1977) will need to distinguish among types of delay procedures.

It should be noted that the 5- and 10-sec durations of unsignaled delay reduced subjects' response rates regardless of whether the rate of reinforcement decreased (under the VI schedule) or increased (under the DRL schedule). In fact, the improvement in the subjects' DRL performance produced by the longer durations of unsignaled delay was a major finding of the present experiment. When reinforcement was not delayed, less than 2% of the responses had IRTs equal to or greater than

Table 3

Percent of responses that were reinforced[a] during the last six sessions under each condition with the DRL schedule.

Bird / delay (sec)	B-3340		B-11629		B-5843		B-1926	
	S[b]	U[c]	S	U	S	U	S	U
.0	—		1.7		.4		.4	
.5	.7	—	1.8	1.5	.4	.8	.6	.3
1.0	.5	5.5	1.0	.9	.8	1.2	1.0	1.0
2.5	.7	16.8	2.1	9.3	.5	10.3	1.1	7.0
5.0	1.3	56.4	1.2	27.7	1.8	25.4	1.8	17.8
10.0	—	39.2	1.5	40.5	1.5	47.1	7.1	60.2

[a]Exclusive of responses during delay and reinforcement periods
[b]Signaled delay
[c]Unsignaled delay

the required 20 sec; such inefficient DRL performance is typical of pigeons (e.g., Reynolds, 1964a, 1964b). However, with a 10-sec unsignaled delay 39 to 60% of the responses, depending on the subject, had IRTs equal to or greater than the required 20 sec. To the author's knowledge, only two other published studies (Meltzer & Brahlek, 1967; Meltzer, Maxey, & Merkler, 1965) have examined the effects of delayed reinforcement on DRL performance. Unfortunately, a comparison between the results of these studies is difficult because Meltzer and his coworkers did not include an immediate reinforcement condition and because they presented only an incomplete interresponse time (IRT) analysis without any actual response rate data. However, the improvement in DRL performance that was observed in the present study is similar to that previously reported when responding was punished with electric shock (Holz, Azrin, & Ulrich, 1963) or timeout (Kramer & Rilling, 1969). The answer to the question of whether these variables improved DRL performance by sharpening the subjects' temporal discrimination or by weakening response strength remains for future research.

While the present study did not investigate processes responsible for lower response rates being maintained by unsignaled than signaled delay at 5- and 10-sec durations, some of this difference, especially the very low rate with unsignaled delay, could be interpreted in terms of adventitious reinforcement and stimulus generalization. With delayed reinforcement, behavior other than key pecking may be followed by food and adventitiously reinforced; the more frequently this other behavior were to occur in the nondelay portions of a session, the more it would compete with key pecking, and the more it would lower response rates (see Spence, 1956). Thus, the magnitude of the disruptive effects of delayed reinforcement should depend on whether other behavior is adventitiously reinforced and on whether this other behavior generalizes to nondelay portions of the session. The signaled delay condition assured that little key pecking would occur during the delay interval and probably allowed adventitious reinforcement of other behavior. While the unsignaled delay condition did not prevent key pecks from occurring during the delay interval, the tendency of VI and DRL schedules to differentially reinforce long interresponse times (IRTs; Reynolds, 1975) also probably assured adventitious reinforcement of behavior other than key pecking. From this perspective, it could be suggested that little disruption of key pecking occurred with signaled delays because the physical dissimilarity of delay and nondelay portions of the session prevented substantial generalization of other behavior to nondelay portions of the session. (The signaled delay condition also may have provided immediate conditioned reinforcement by the onset of the signal, as discussed by Spence, 1947). But, with unsignaled delays, much disruption of key pecking occurred because the delay and nondelay portions of the session were physically identical, thus producing substantial generalization of other behavior to nondelay portions of the session. While speculative, this interpretation could be tested by systematically varying the similarity of the delay and nondelay portions of a session during either training or in a test session with a probe technique. A version of this adventitious reinforcement hypothesis might also explain why some birds showed higher response rates with brief unsignaled delay than with immediate reinforcement. As previously noted, VI and DRL schedules of immediate reinforcement may differentially reinforce long IRT's. Given the tendency for responses to occur in bursts (i.e., in a series of short IRT's; see Reynolds, 1975), a short unsignaled delay would allow adventitious reinforcement of short IRT's in both schedules and thus produce higher rates of response than immediate reinforcement (Sizemore & Lattal, 1978, also employed this type of explanation for a similar finding in their study). Since the duration of a burst is typically brief, such differential reinforcement of short IRT's would be expected at brief durations but not at longer delays where behavior other than key pecking would be more likely to be adventitiously reinforced. From this perspective, facilitation should not occur in schedules such as a variable-ratio or fixed-ratio that may already differentially reinforce these short IRT's. In future research, it would be useful to record the number of responses and the IRTs that occur during each unsignaled delay interval. Such a procedure would also allow the researcher to specify the actual (not merely the nominal) delay durations and to construct an identical sequence of signaled delay durations that could be used to more directly compare signaled and unsignaled delays. In fact, in future research with VI schedules, it would be useful for researchers to use a similar yoking procedure to construct a VI schedule for signaled delay and immediate reinforcement, as well as response-independent schedules, based on the actual interreinforcement-intervals obtained with unsignaled delay.

Finally, it should be noted that the present results were obtained by comparing the signaled and unsignaled delays at each duration during successive 24 session blocks and that a different experimental design may have produced a somewhat different outcome. Although the relative effects of signaled vs. unsignaled delay at each duration was unaffected by whether the first block involved signaled or unsignaled delay, it might be useful for future research to make these comparisons by having each delay condition follow the same baseline condition (e.g., immediate reinforcement) and also to determine if a subject's prior training alters the absolute and/or relative shapes of the delay of reinforcement gradients.

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